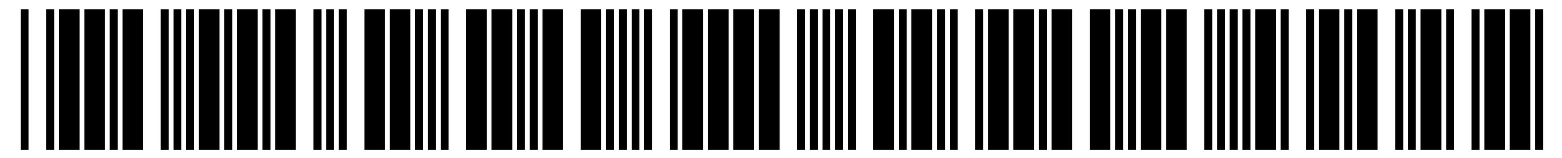

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Nishihara et al.

(10) **Patent No.: US 6,734,763 B2**
(45) **Date of Patent: May 11, 2004**

(54) **THIN-FILM PIEZOELECTRIC RESONATOR, BAND-PASS FILTER AND METHOD OF MAKING THIN-FILM PIEZOELECTRIC RESONATOR**

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(73) Assignees: **Fujitsu Limited**, Kawasaki (JP); **Fujitsu Media Devices Limited**, Suzaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/117,219**

(22) Filed: **Apr. 8, 2002**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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Jan. 23, 2002 (JP) 2002-013984

(51) **Int. Cl.**^{7} **H03H 9/00**
(52) **U.S. Cl.** **333/187**; 333/188; 29/25.35
(58) **Field of Search** 333/187–192; 29/25.35

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Primary Examiner—Kenneth B. Wells
(74) *Attorney, Agent, or Firm*—Armstrong, Kratz, Quintos, Hanson & Brooks, LLP

(57) **ABSTRACT**

A thin-film piezo-resonator includes a silicon substrate and a resonator assembly. The substrate is formed with a cavity or through-hole which is opened in the upper and the lower surfaces of the substrate. The resonator assembly, disposed at a location corresponding to the cavity, is composed of a first electrode contacting the upper surface of the substrate, a piezoelectric layer formed on the first electrode and a second electrode formed on the piezoelectric layer. The cavity has a side surface extending in a substantially perpendicular direction to the first surface.

26 Claims, 16 Drawing Sheets

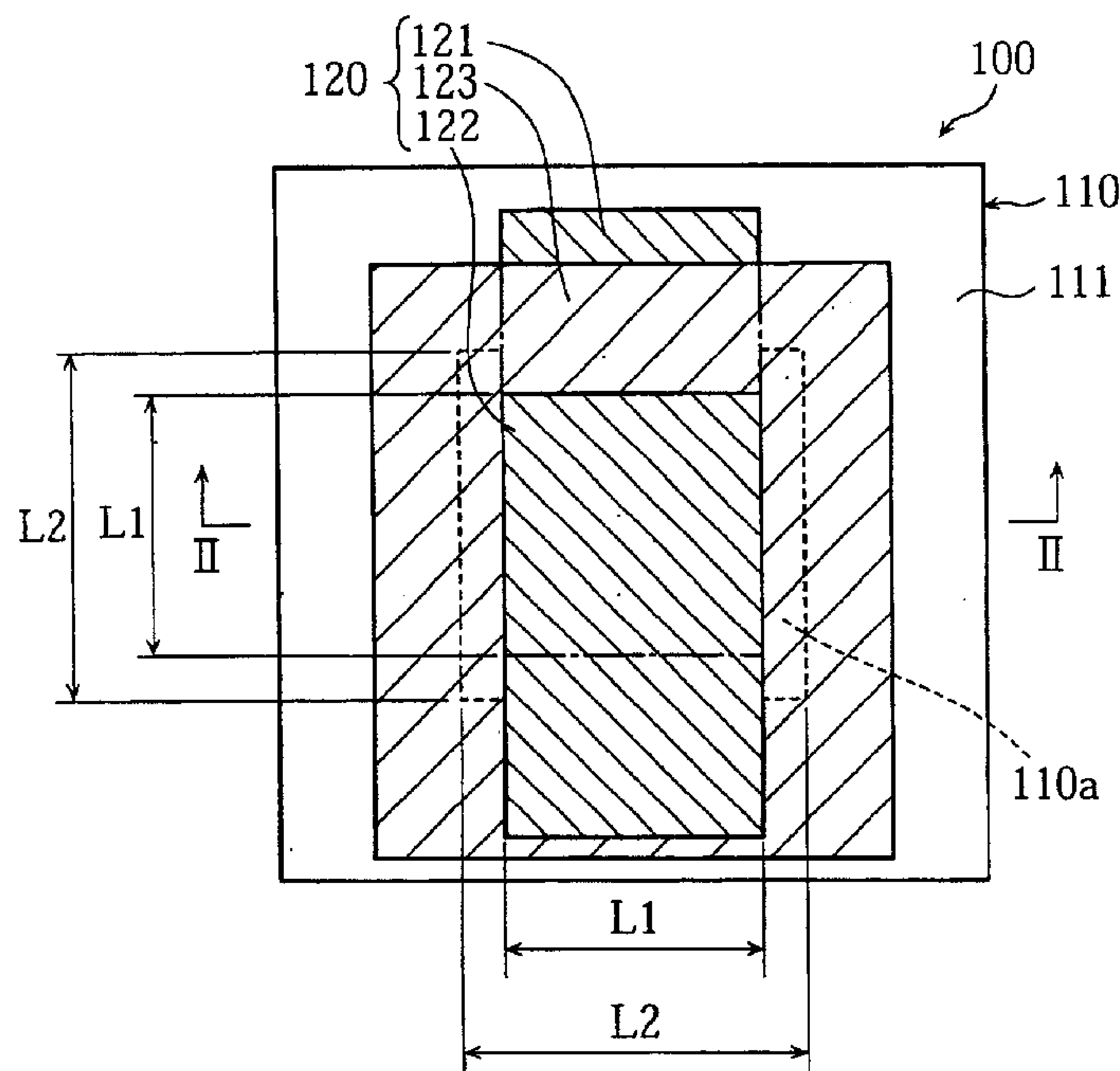


FIG.1

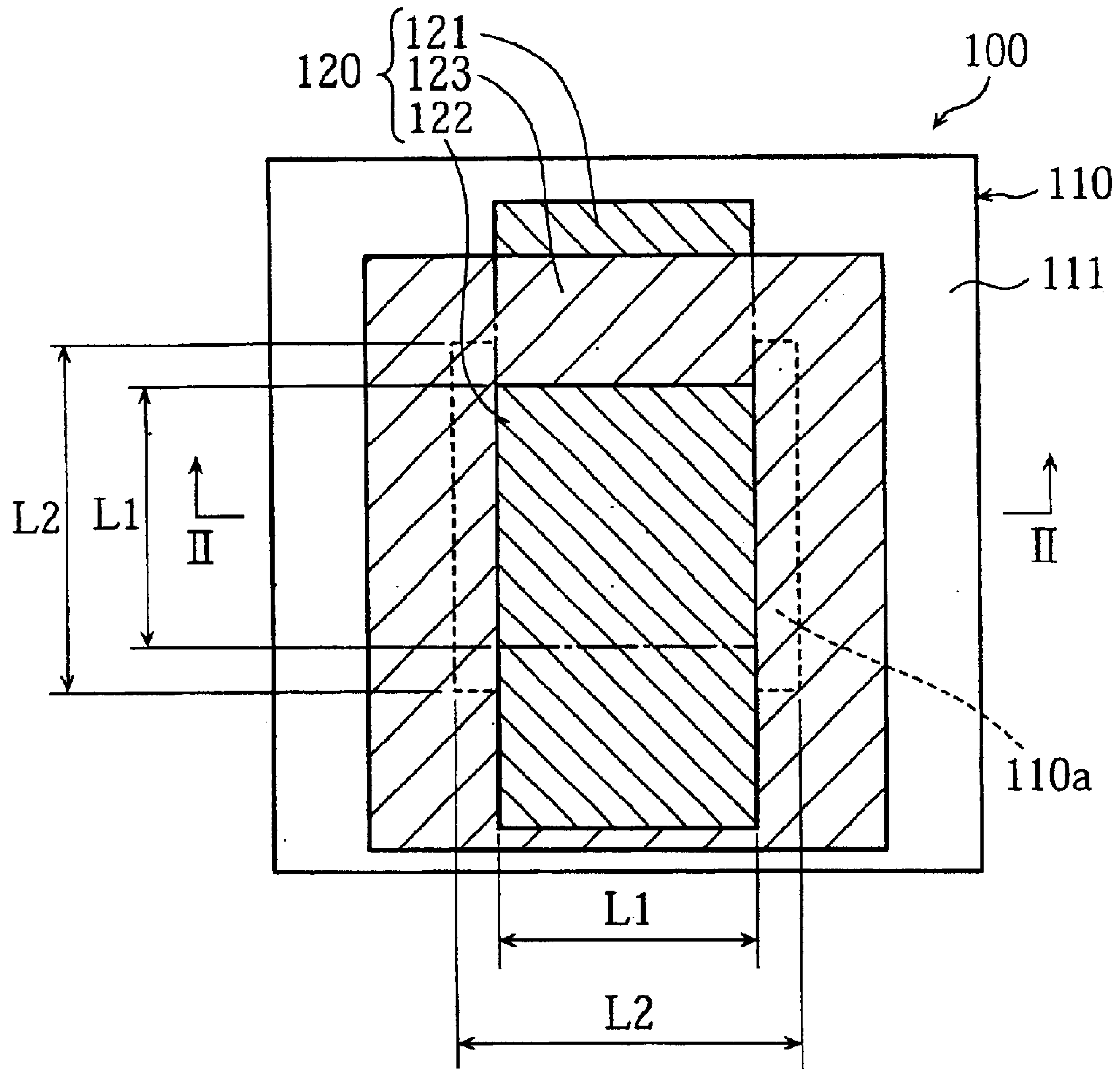


FIG.2

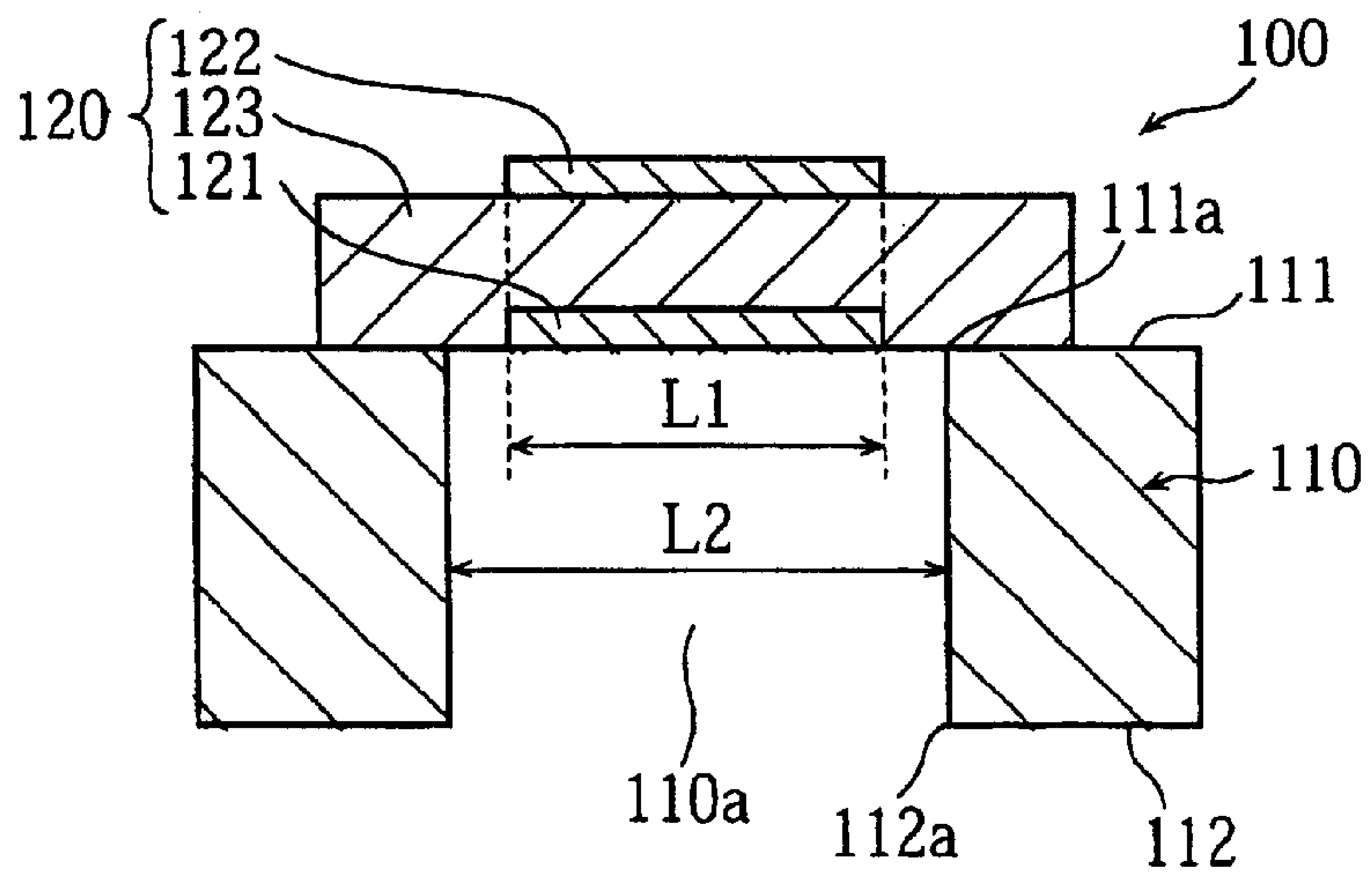


FIG.3

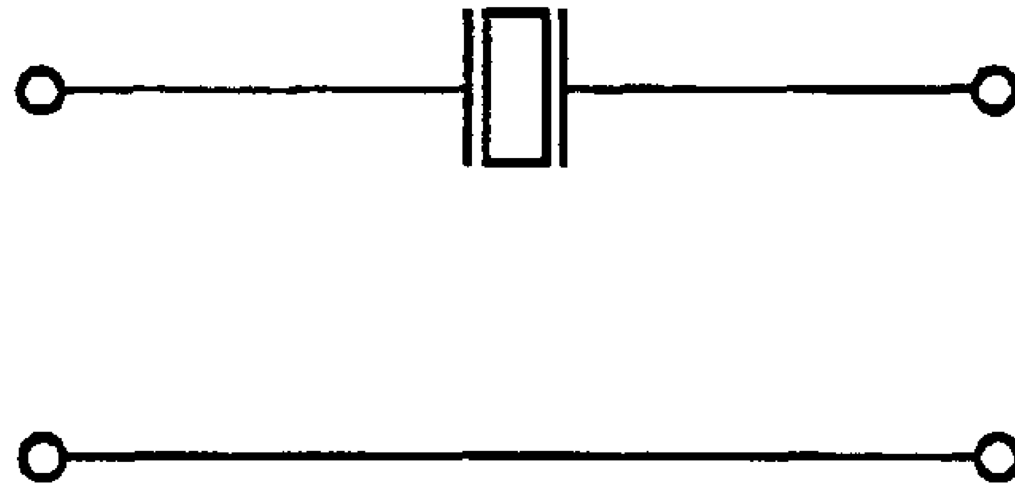


FIG.4

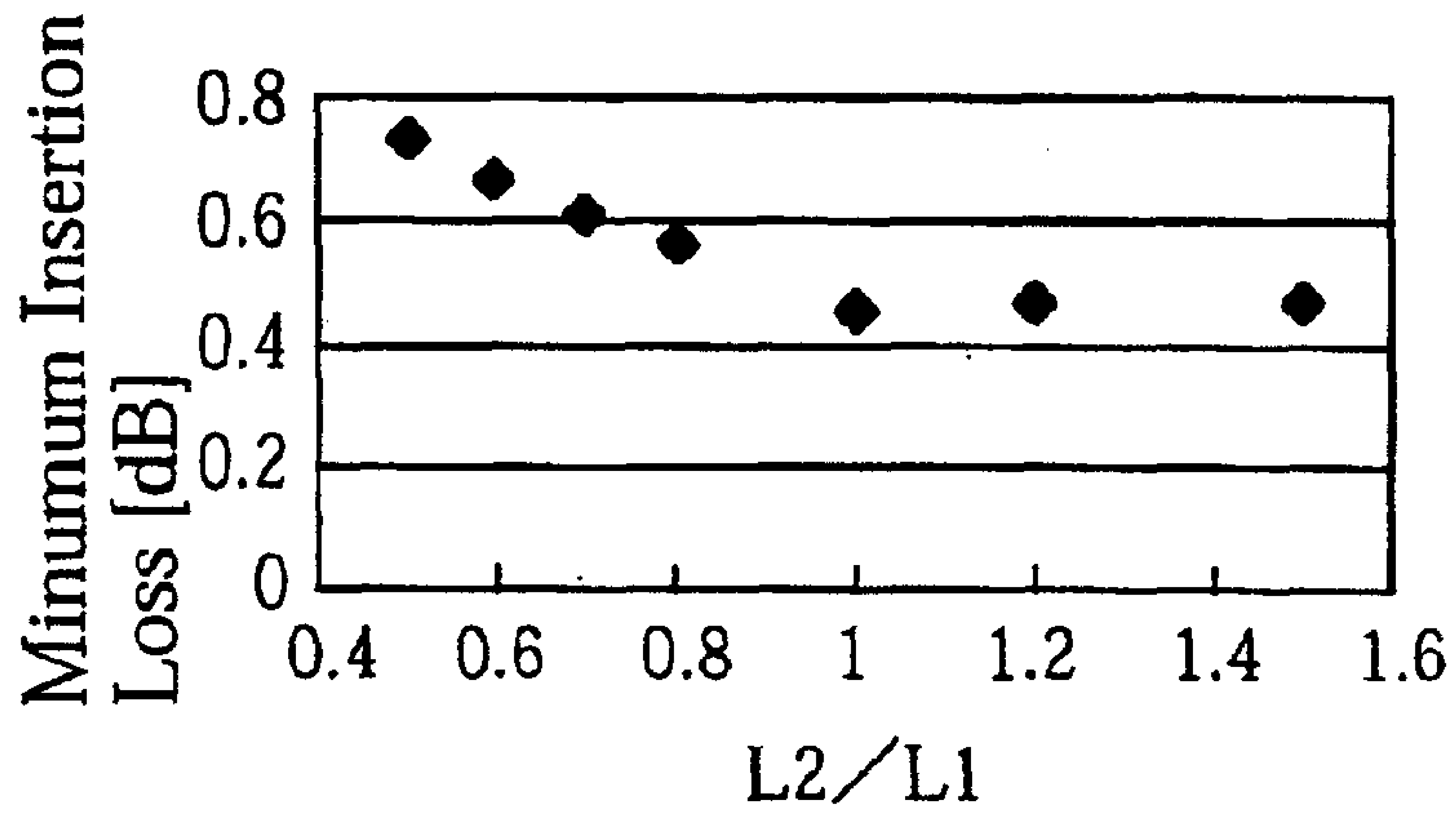


FIG.5

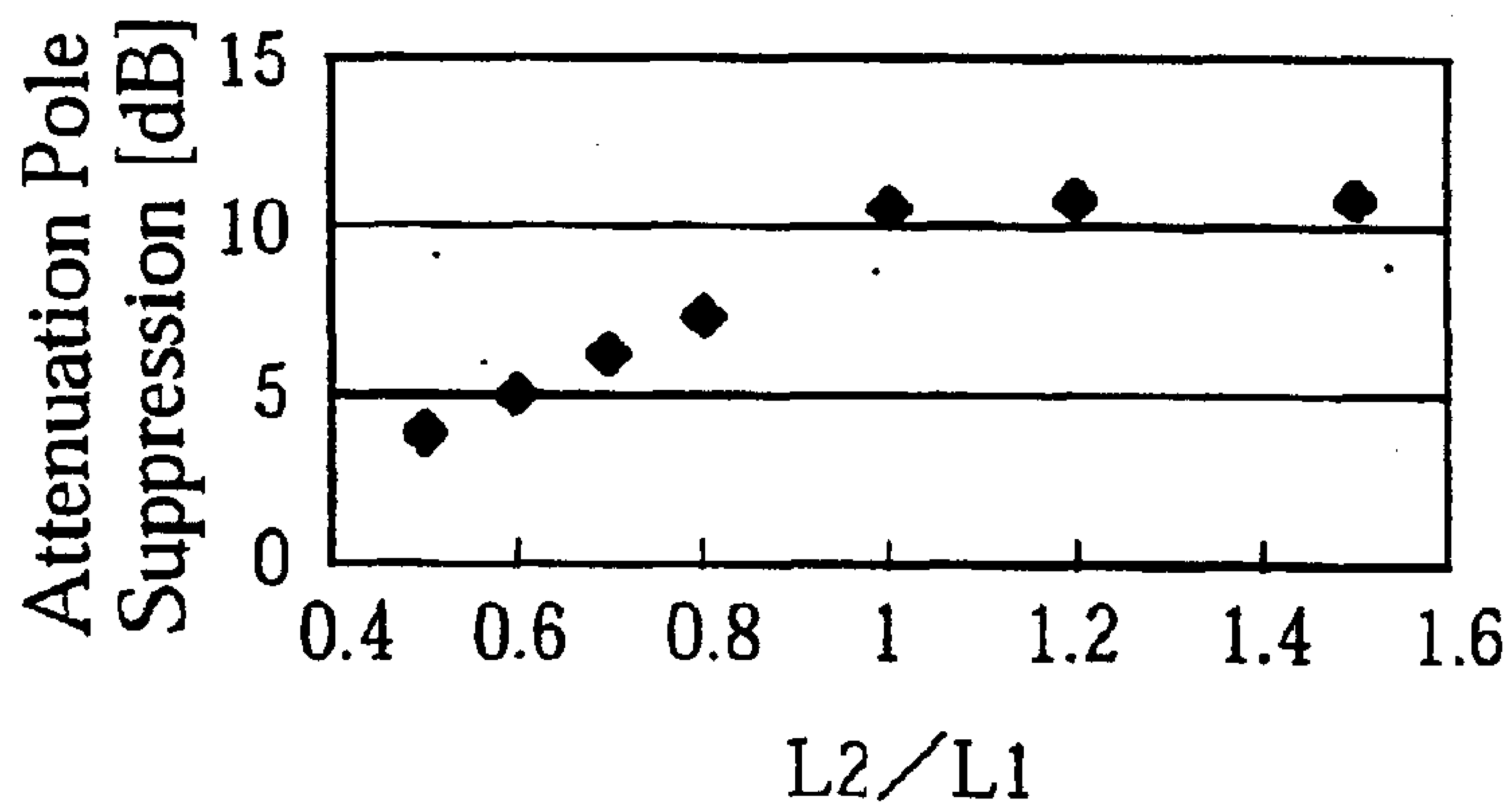


FIG.6A

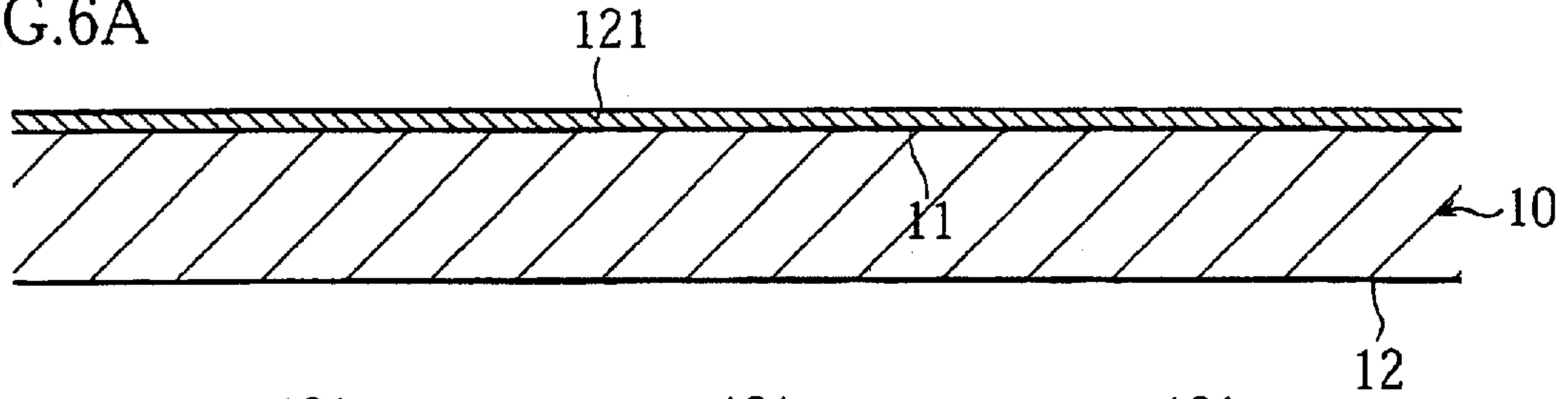


FIG.6B

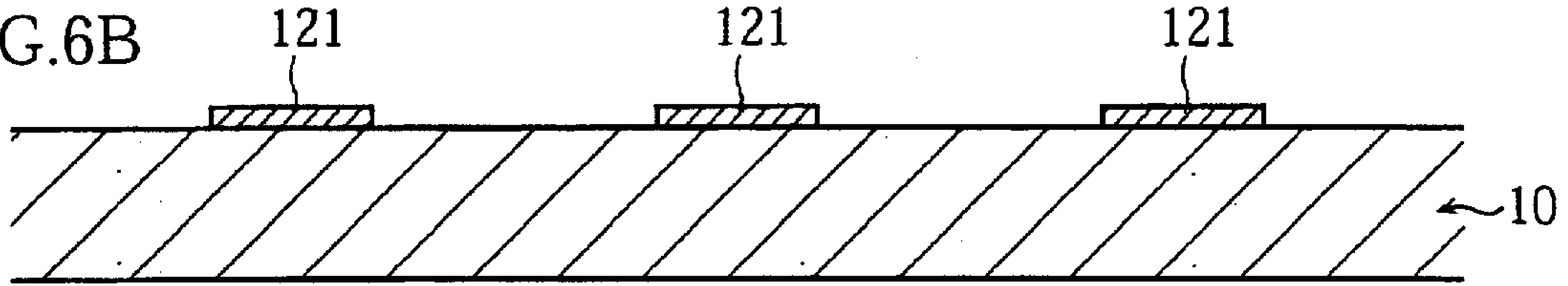


FIG.6C

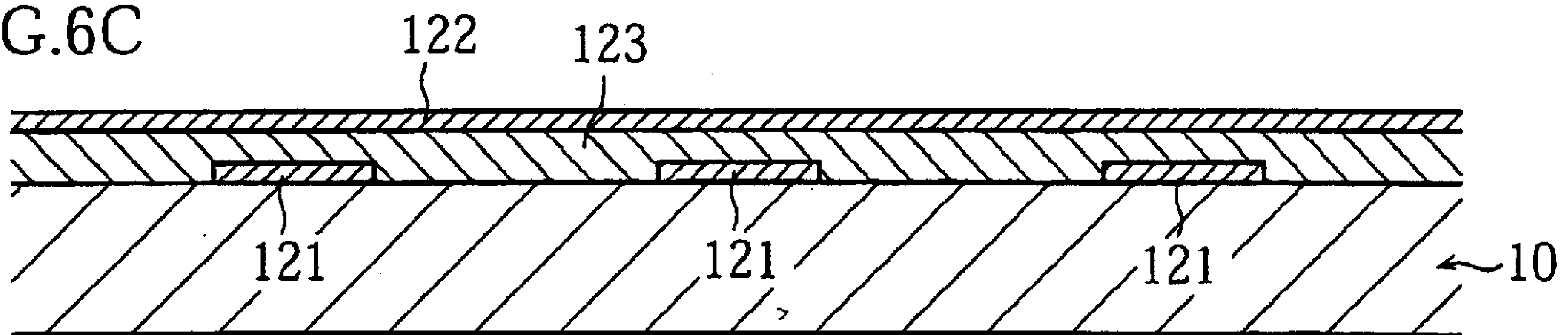


FIG.6D

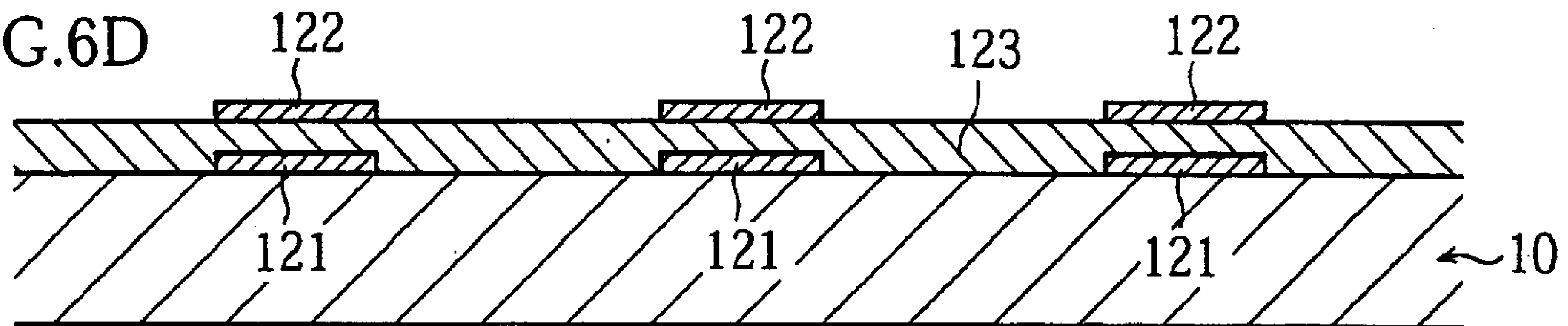


FIG.6E

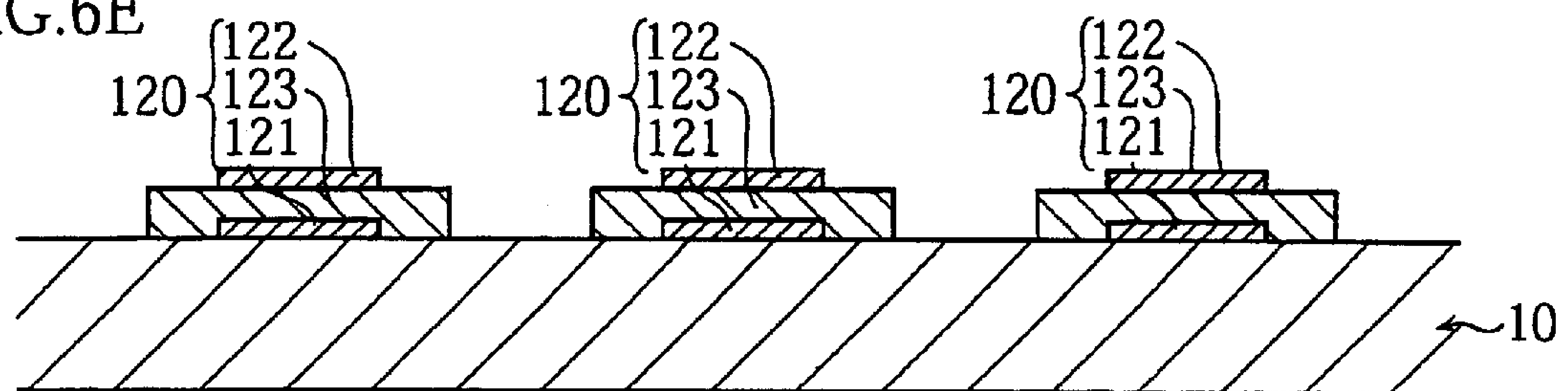


FIG.7A

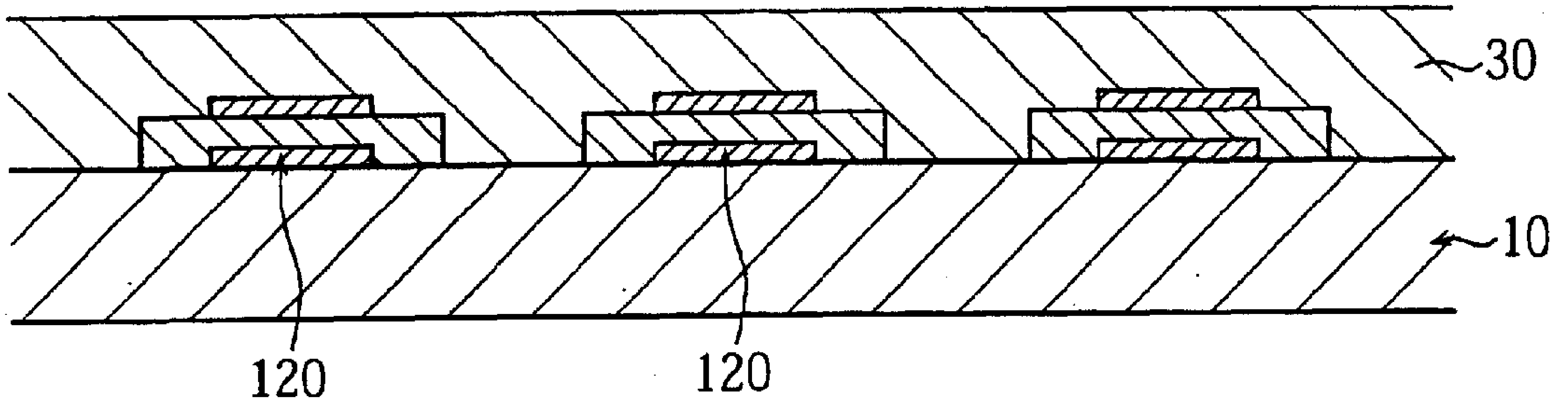


FIG.7B

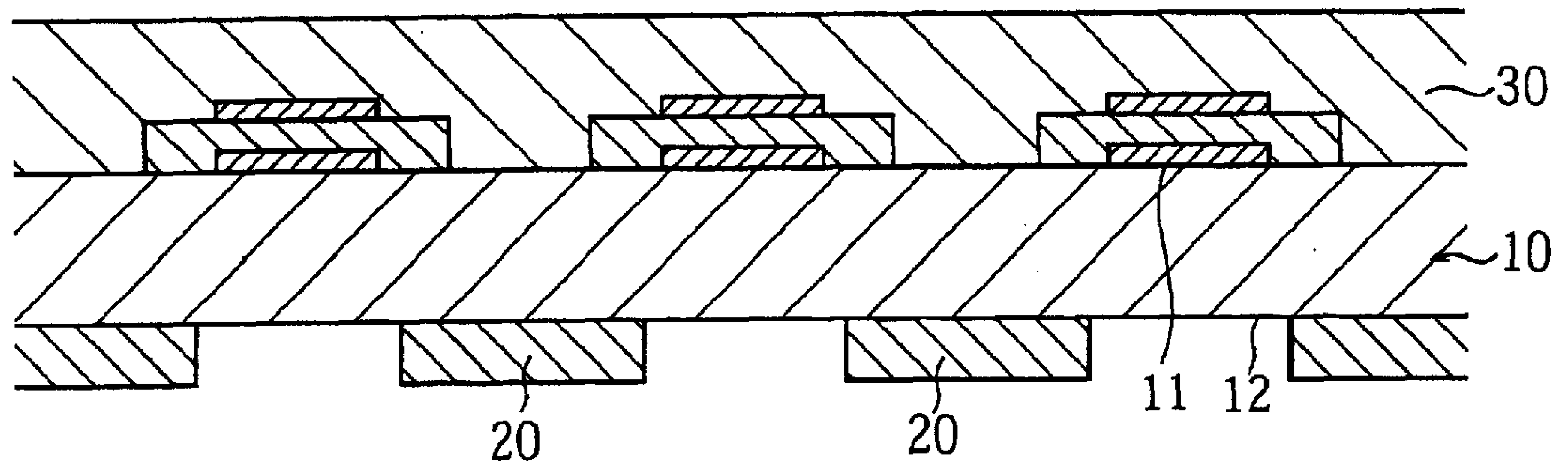


FIG.7C

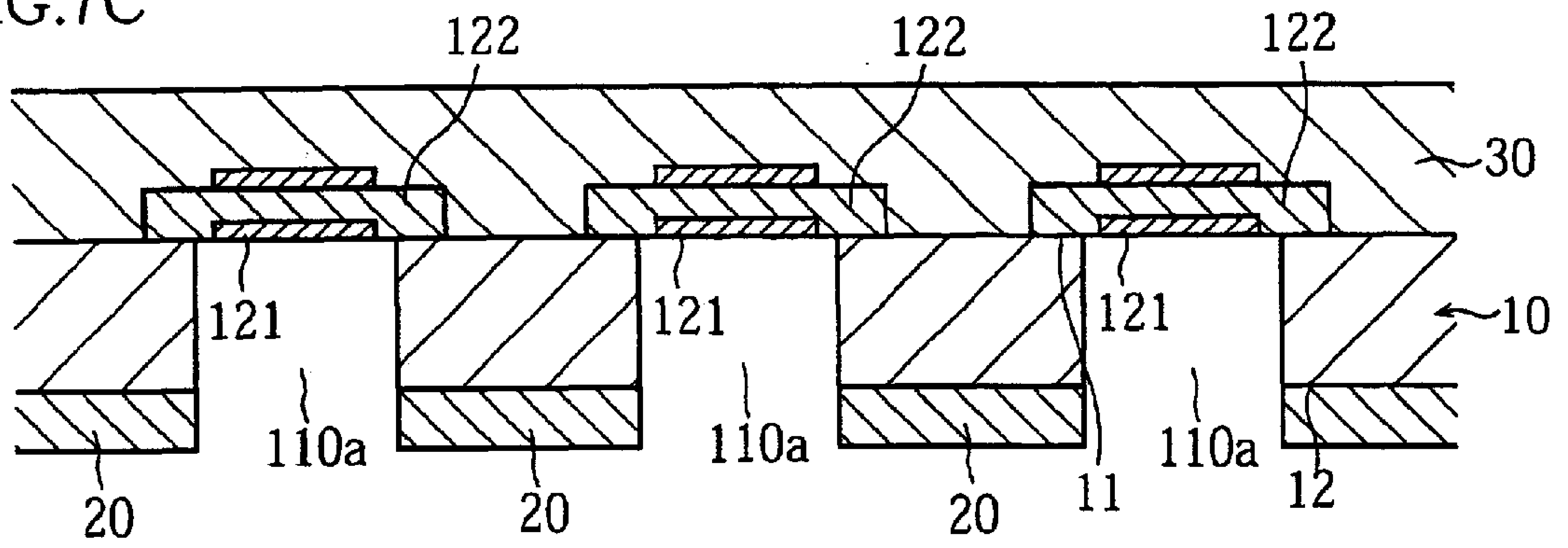


FIG.7D

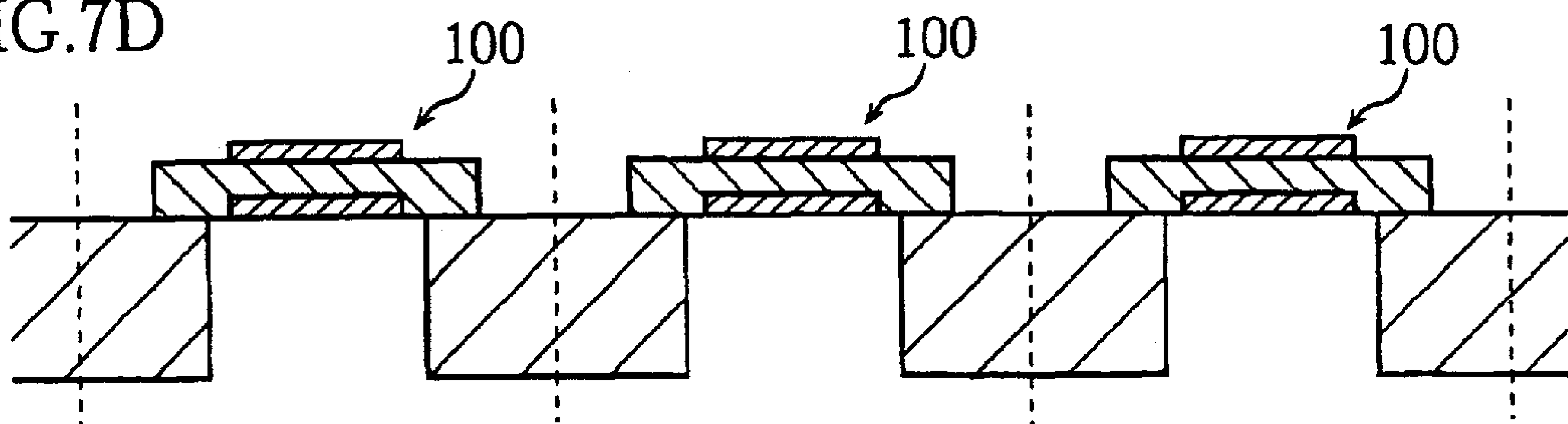


FIG.8

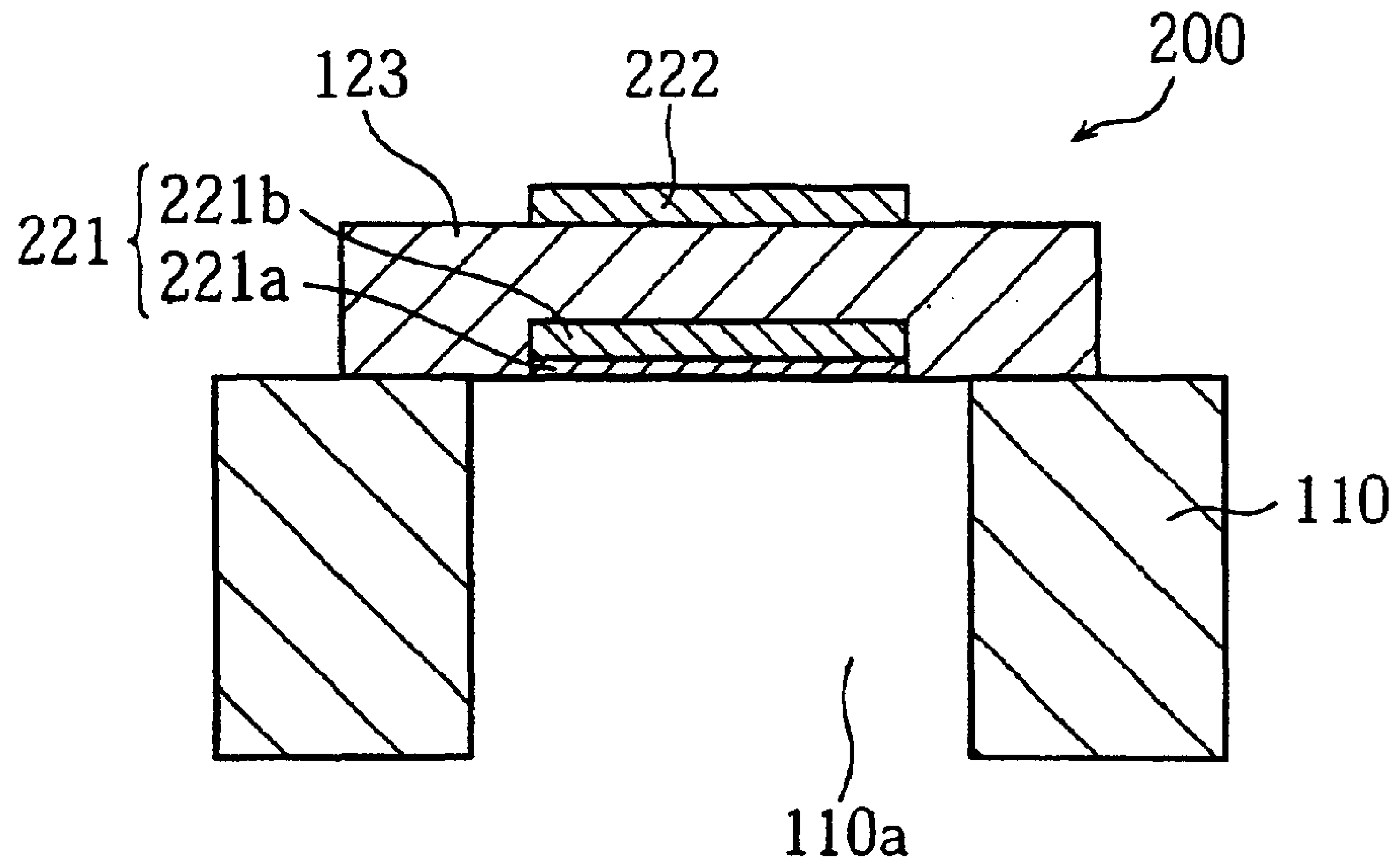


FIG.9

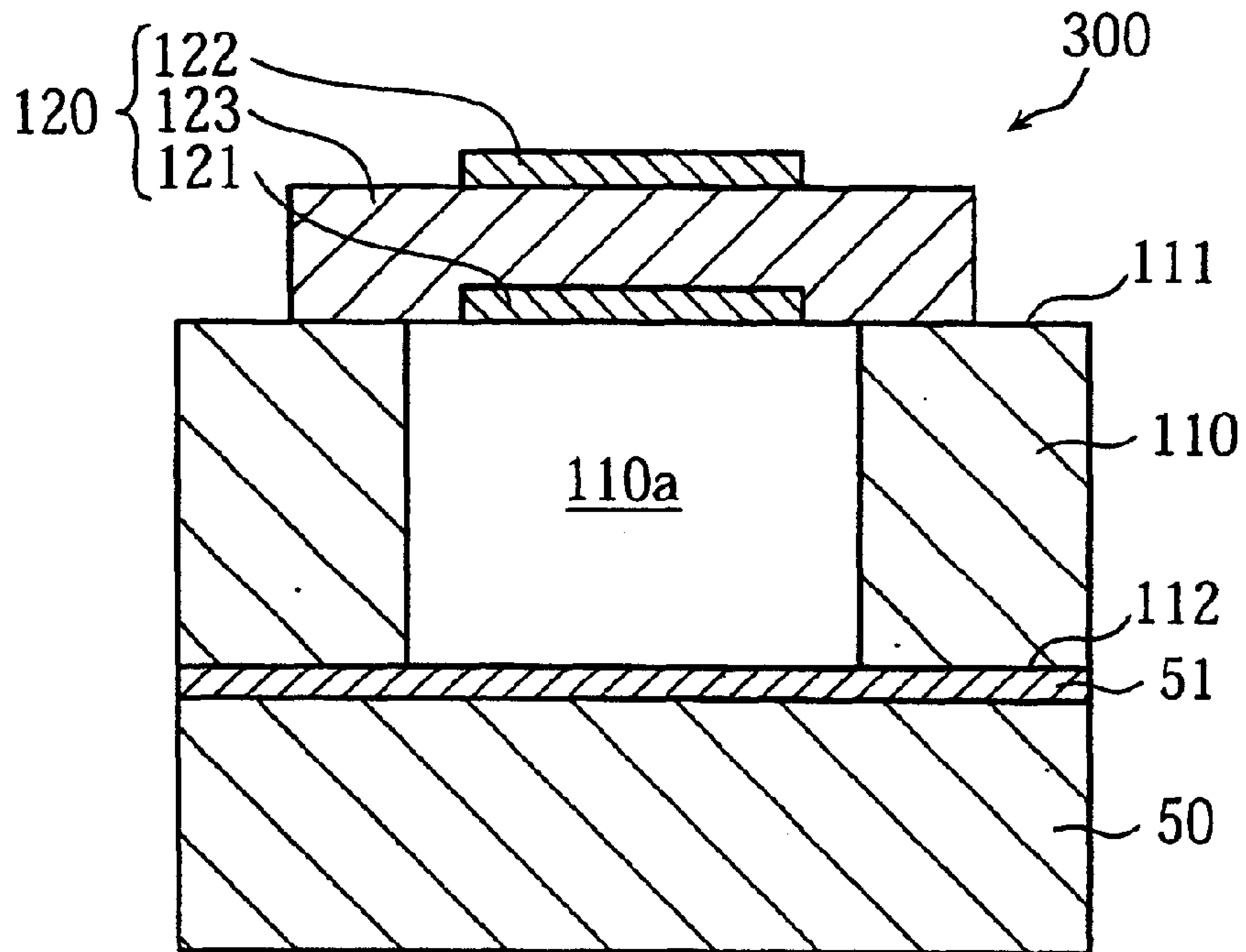


FIG.10

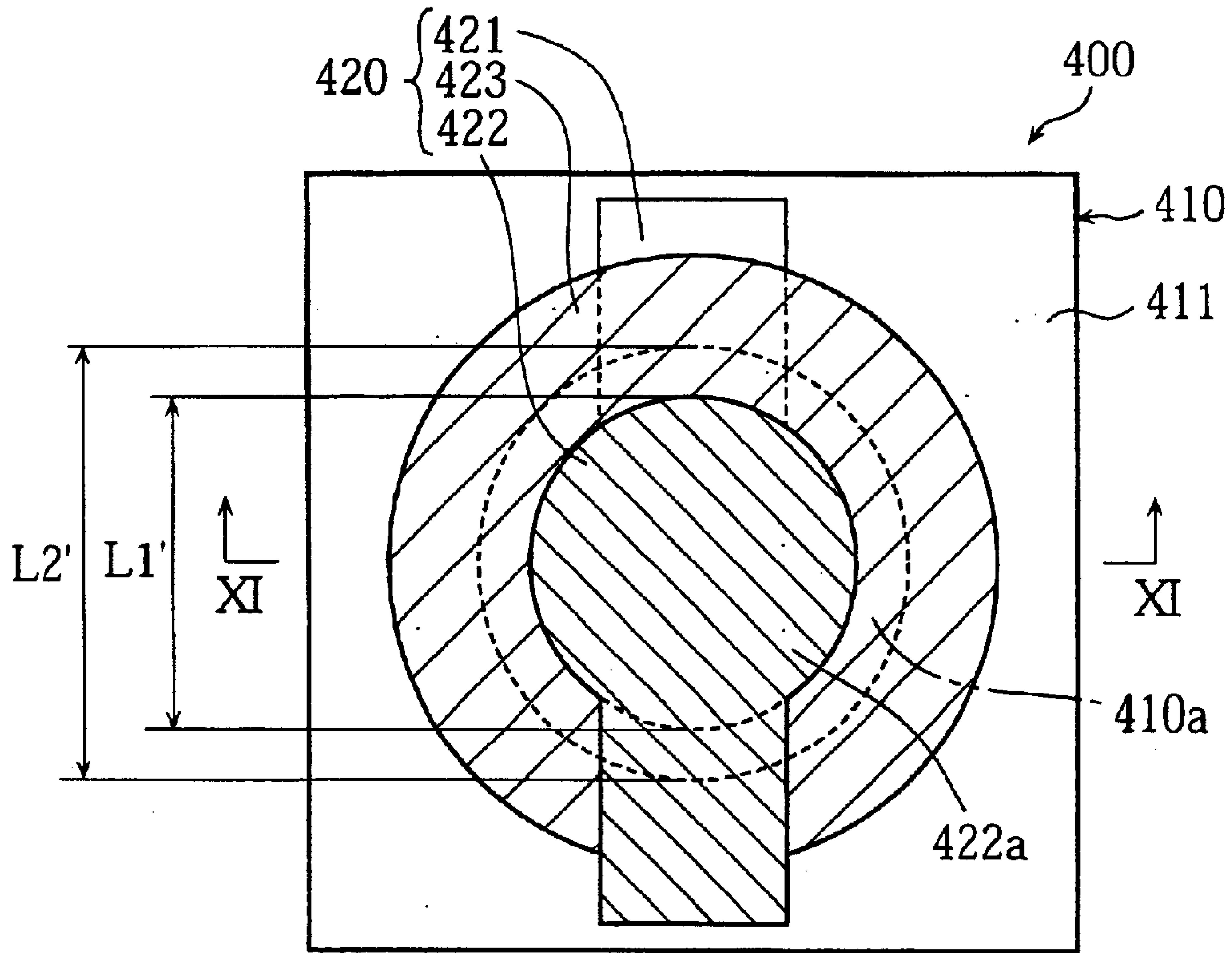
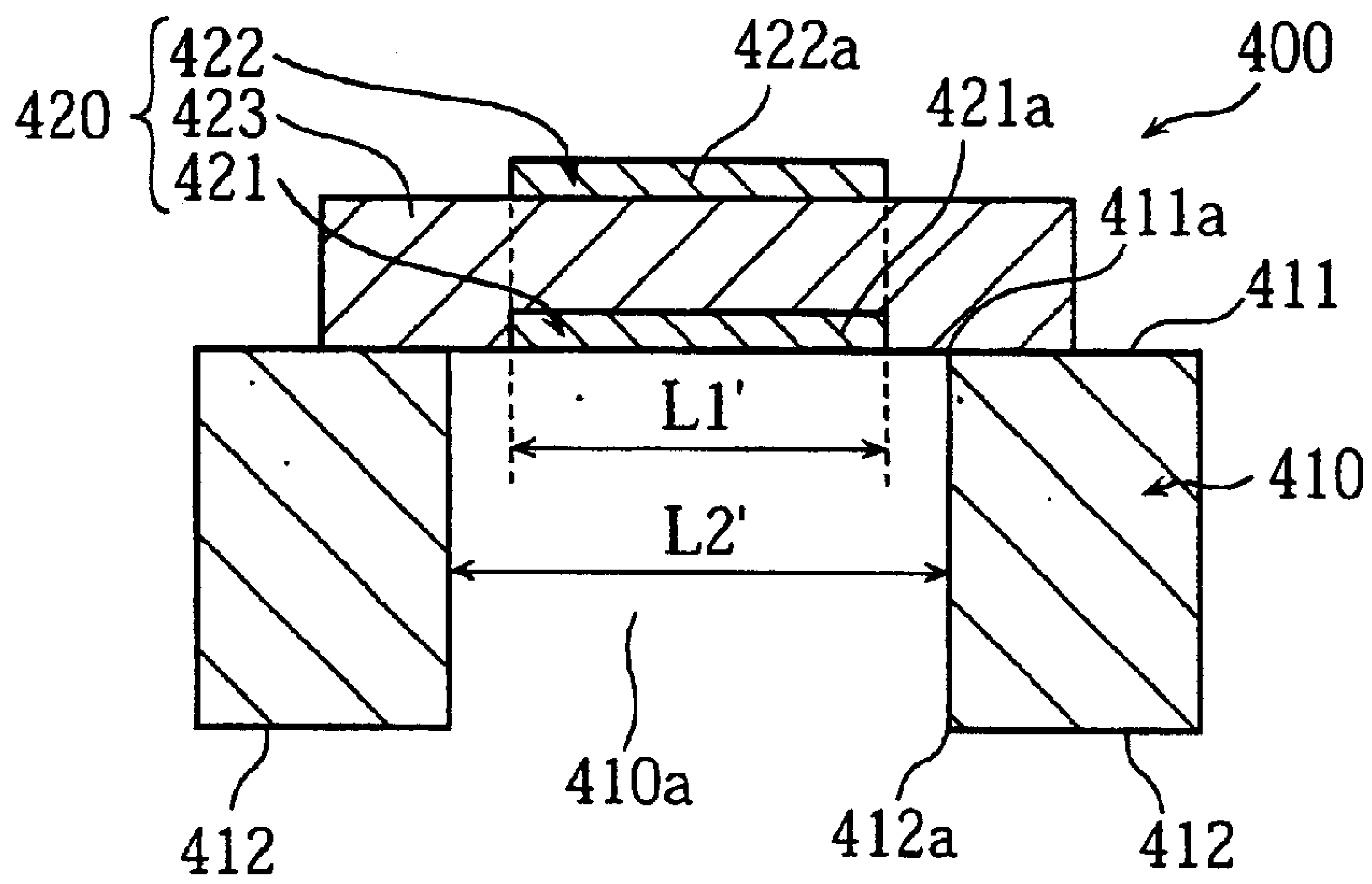


FIG.11



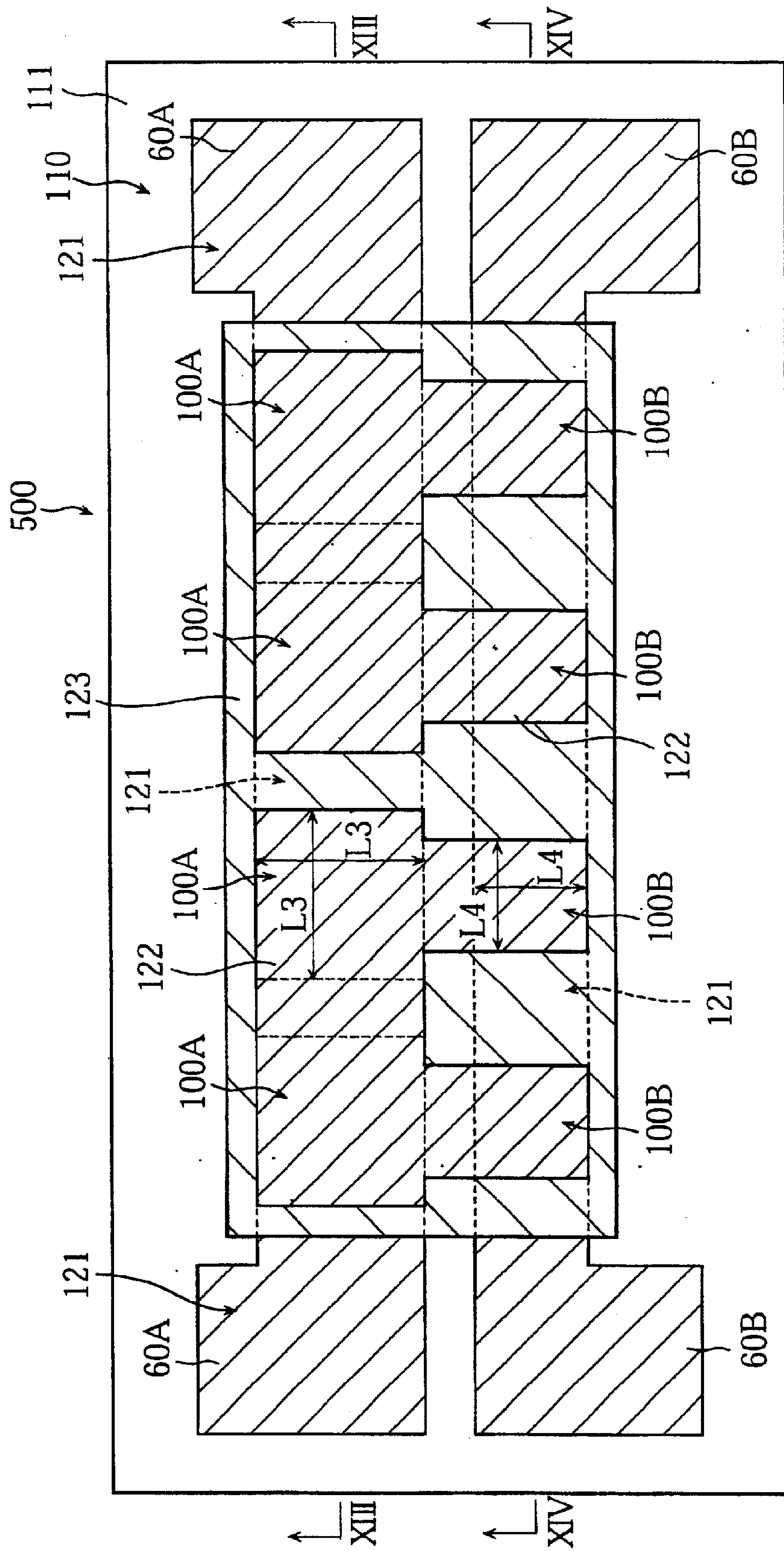


FIG.12
XIII
XIV
111
110
121
60A
60B
100A
100B
500
123
122
L3
L4

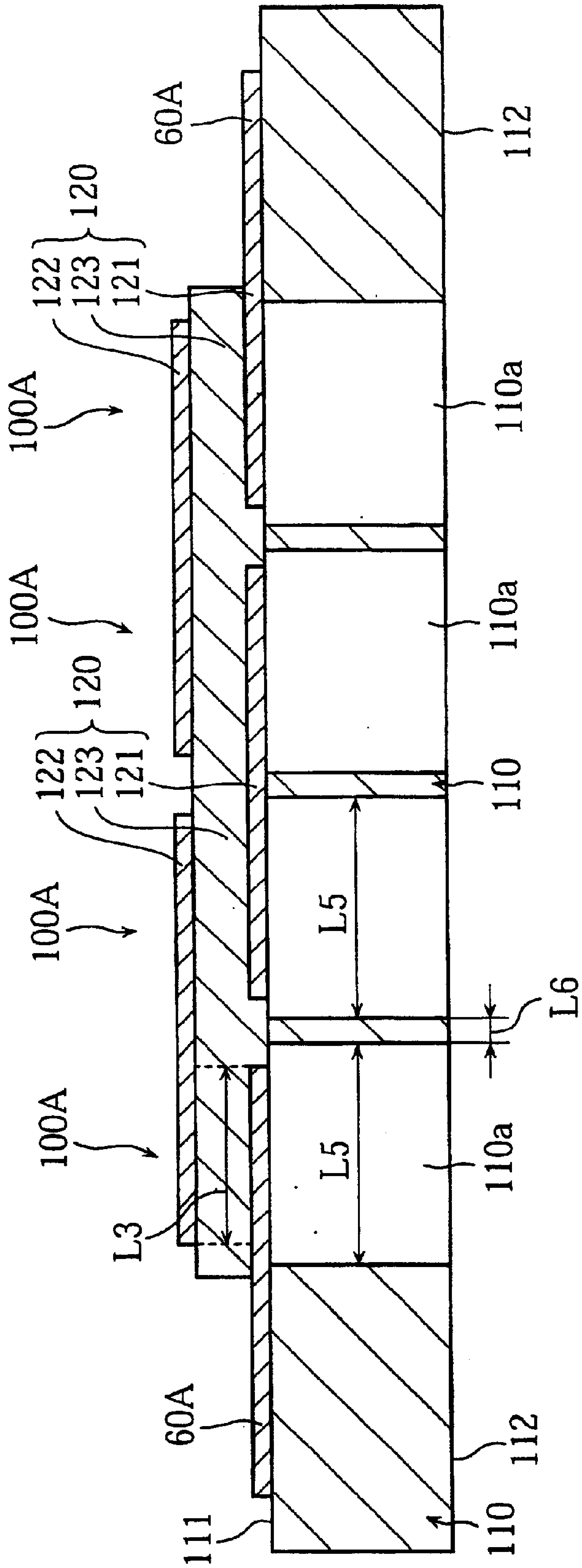


FIG.13

FIG.14

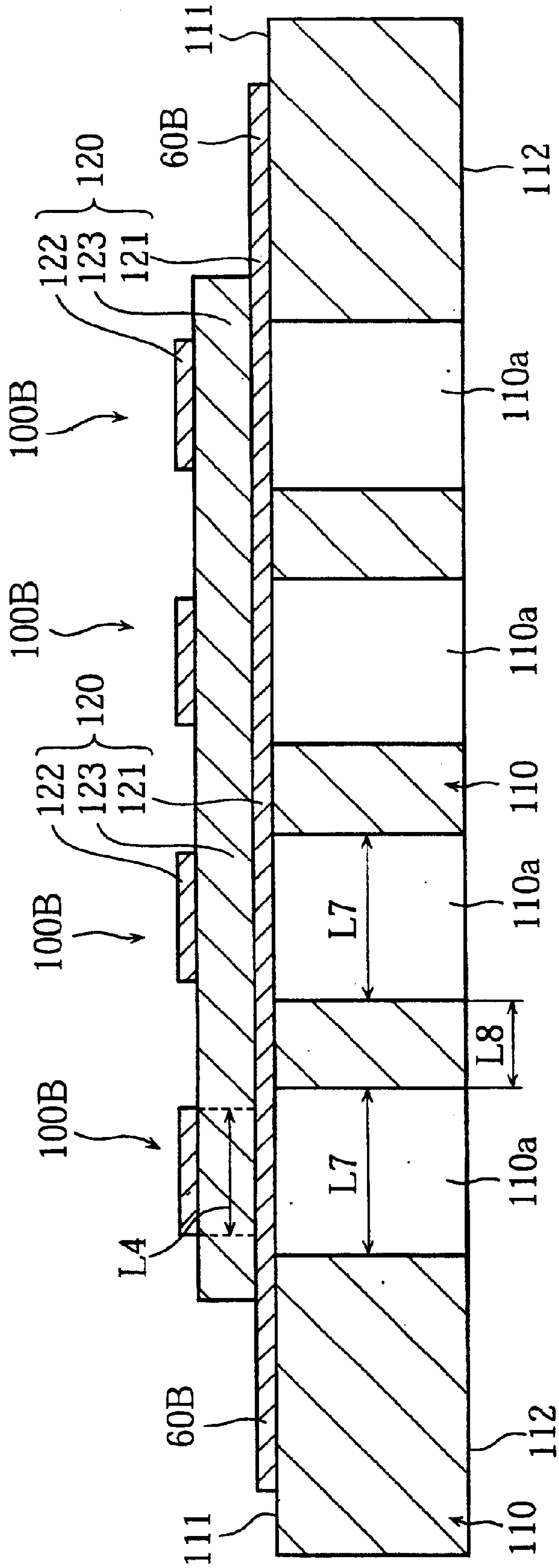
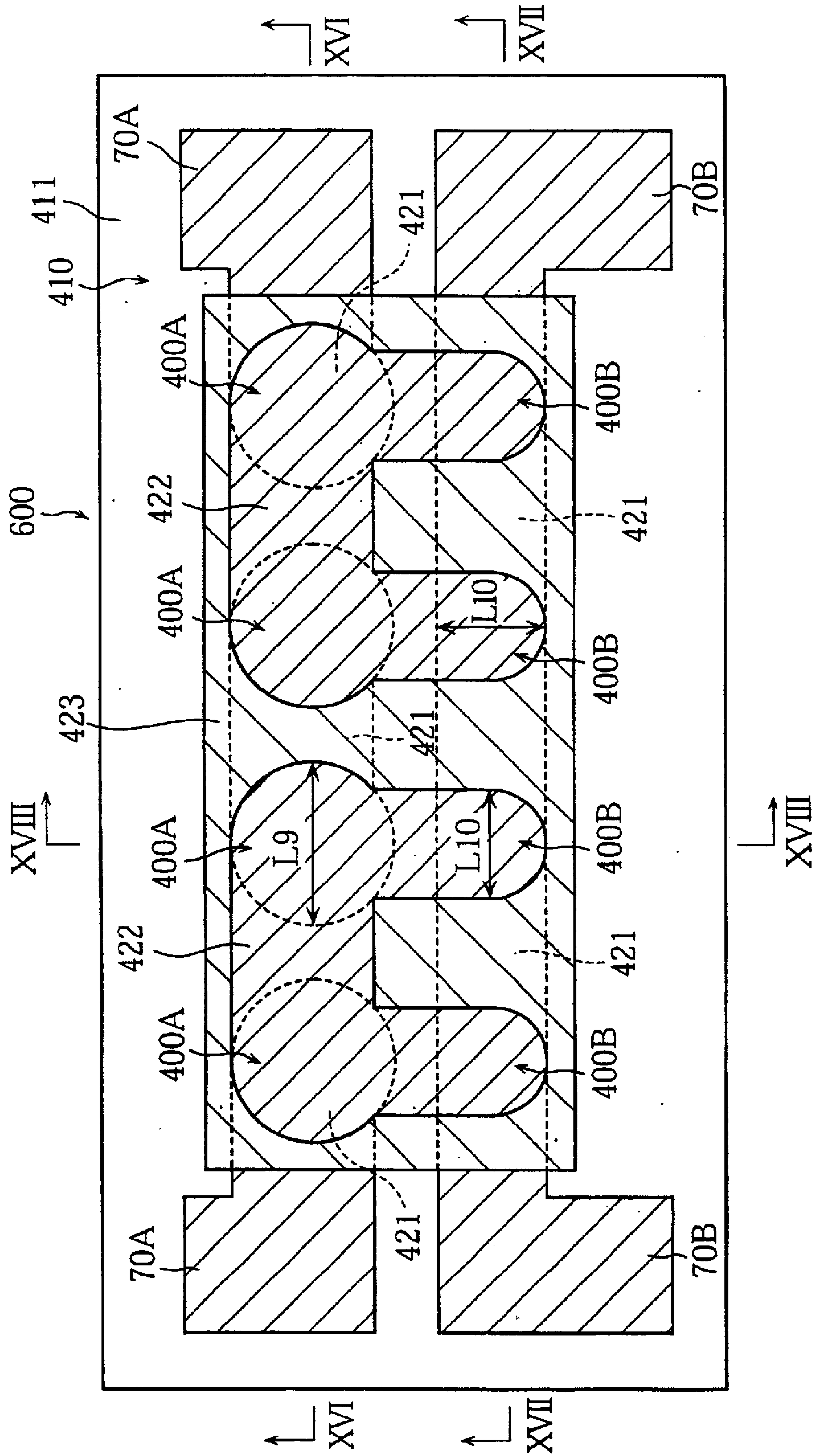


FIG.15



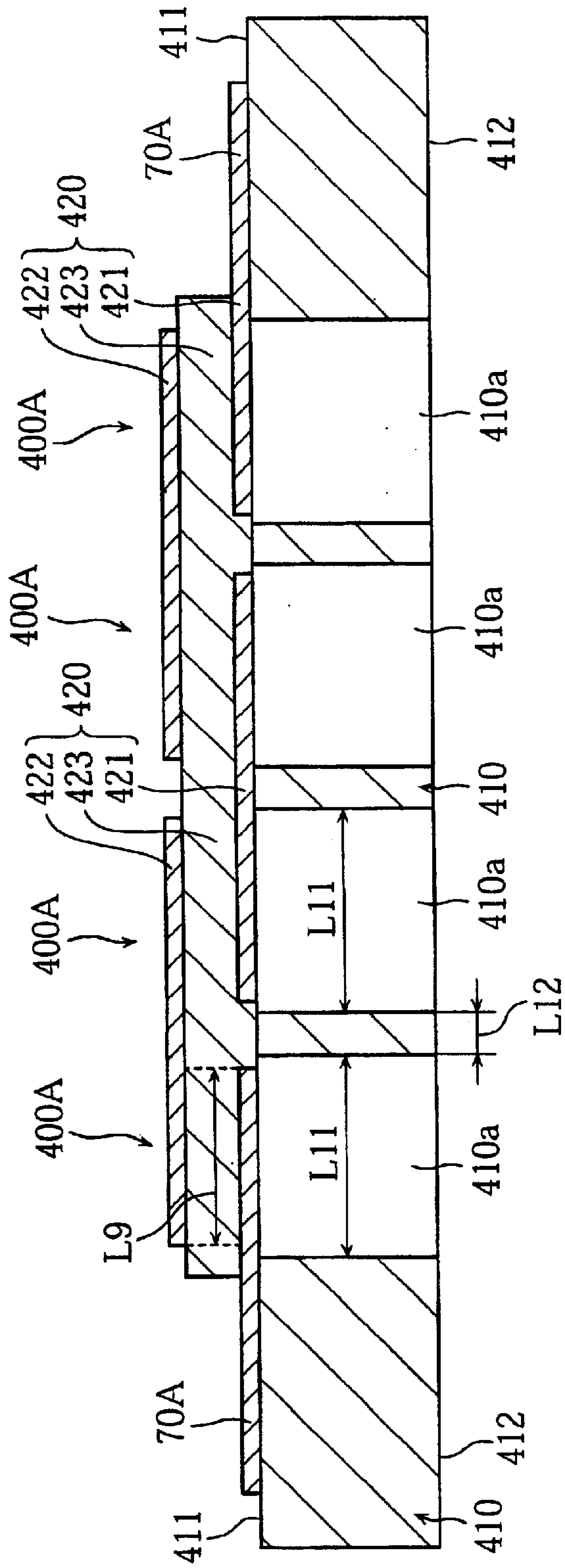


FIG.16
411
412
70A
420
422
423
421
400A
410a
410
L11
L12
L9

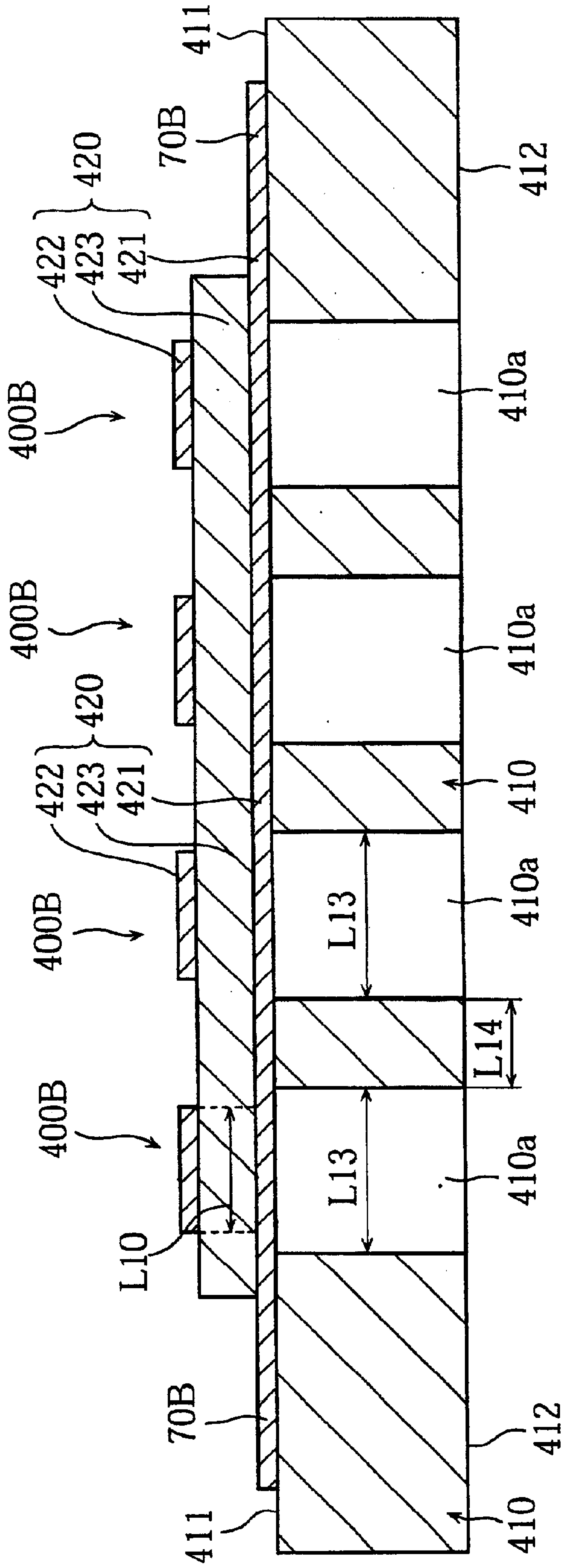
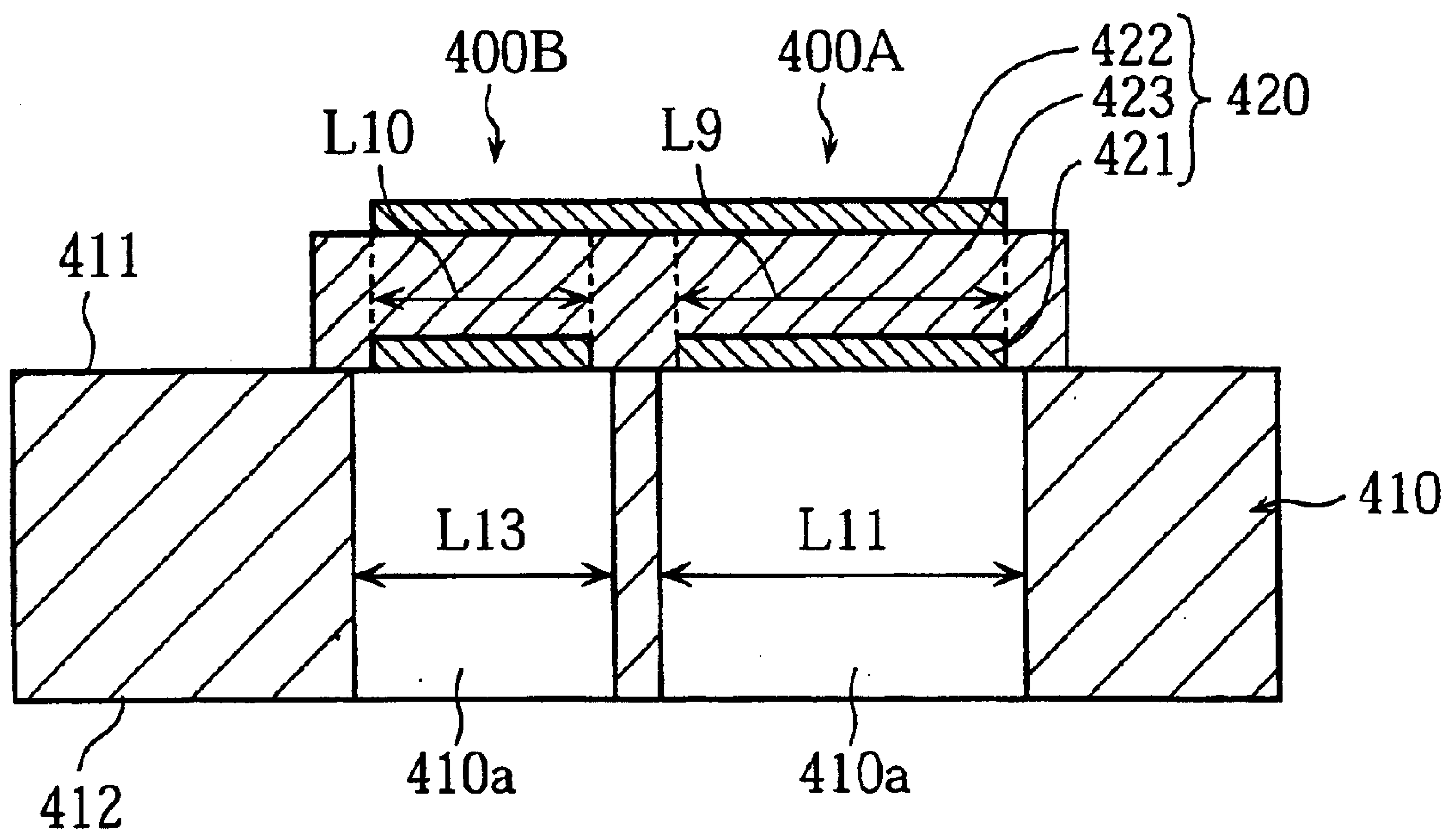


FIG.17
411
70B
420
422
423
421
400B
412
410a
410
L13
L14
L10

FIG.18



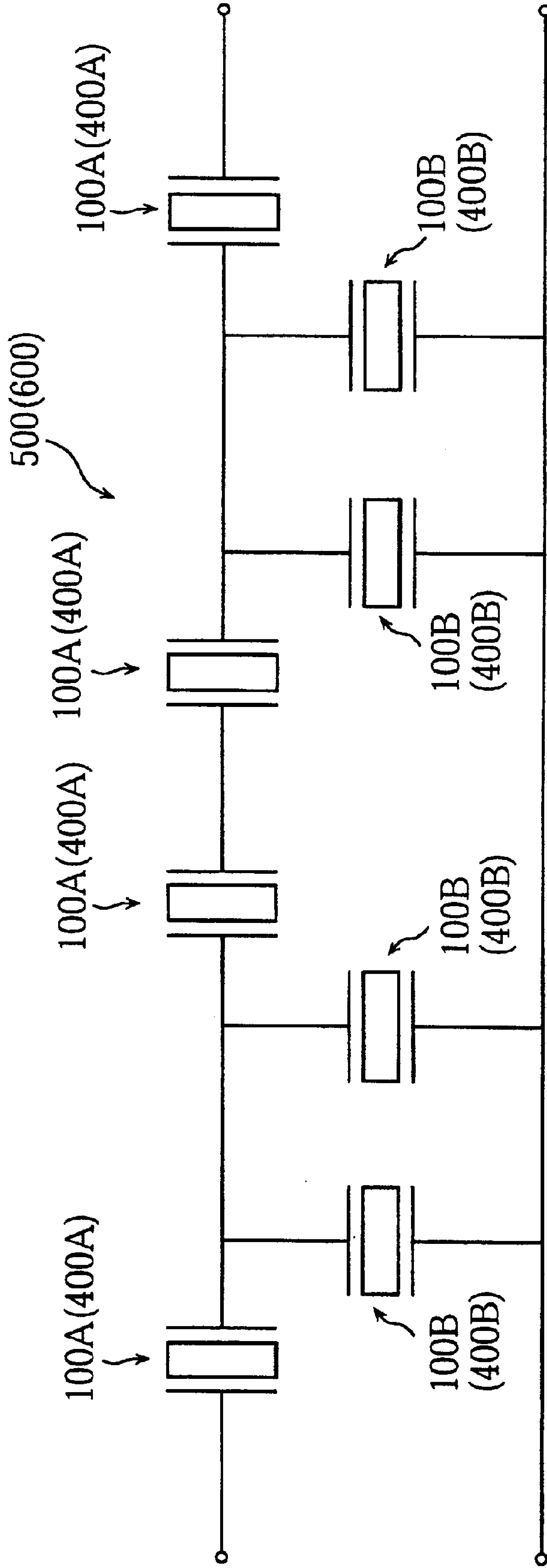


FIG.19
500(600)
100A(400A)
100A(400A)
100A(400A)
100A(400A)
100B (400B)
100B (400B)
100B (400B)
100B (400B)

FIG.20
PRIOR ART

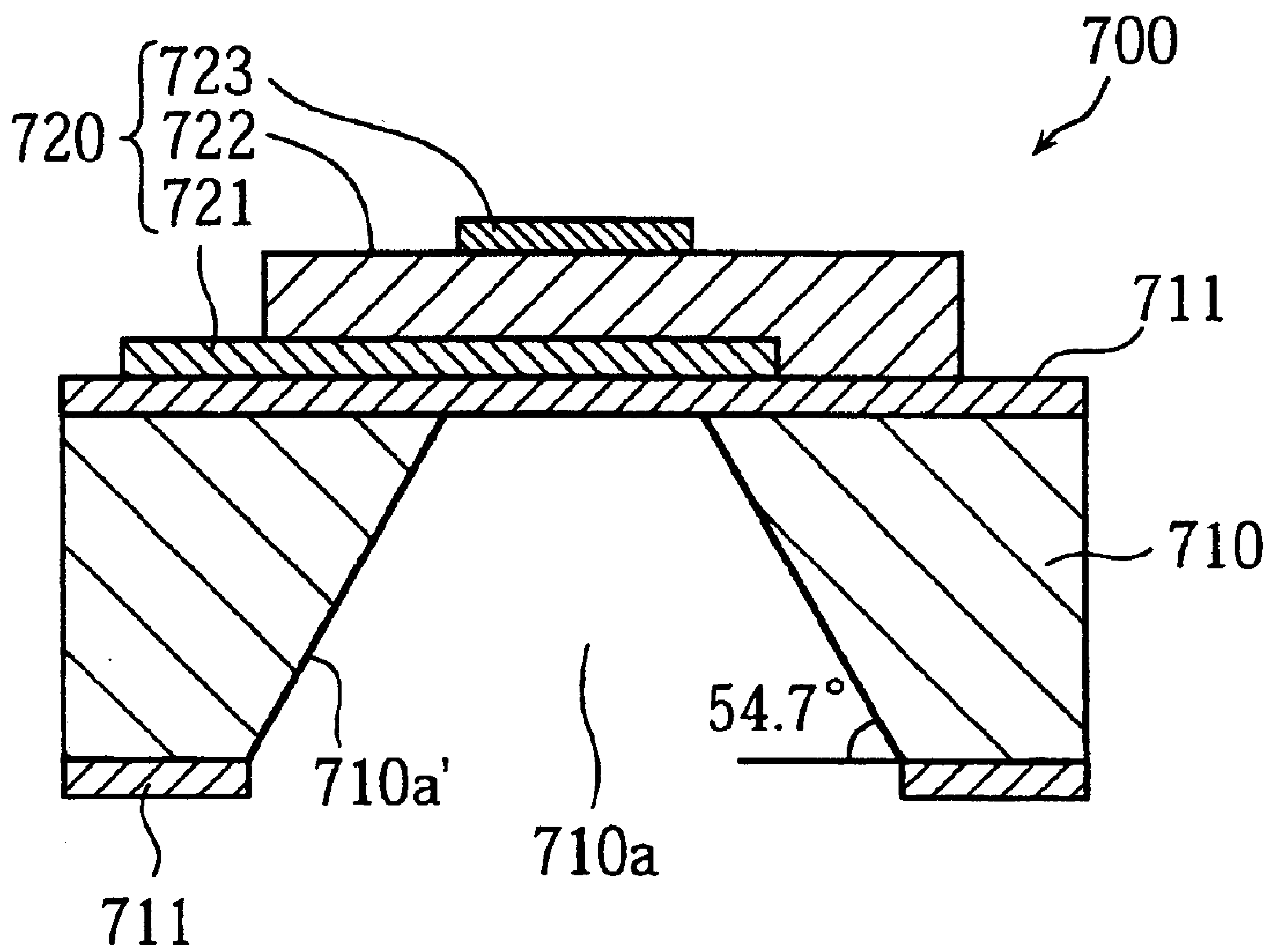


FIG.21
PRIOR ART

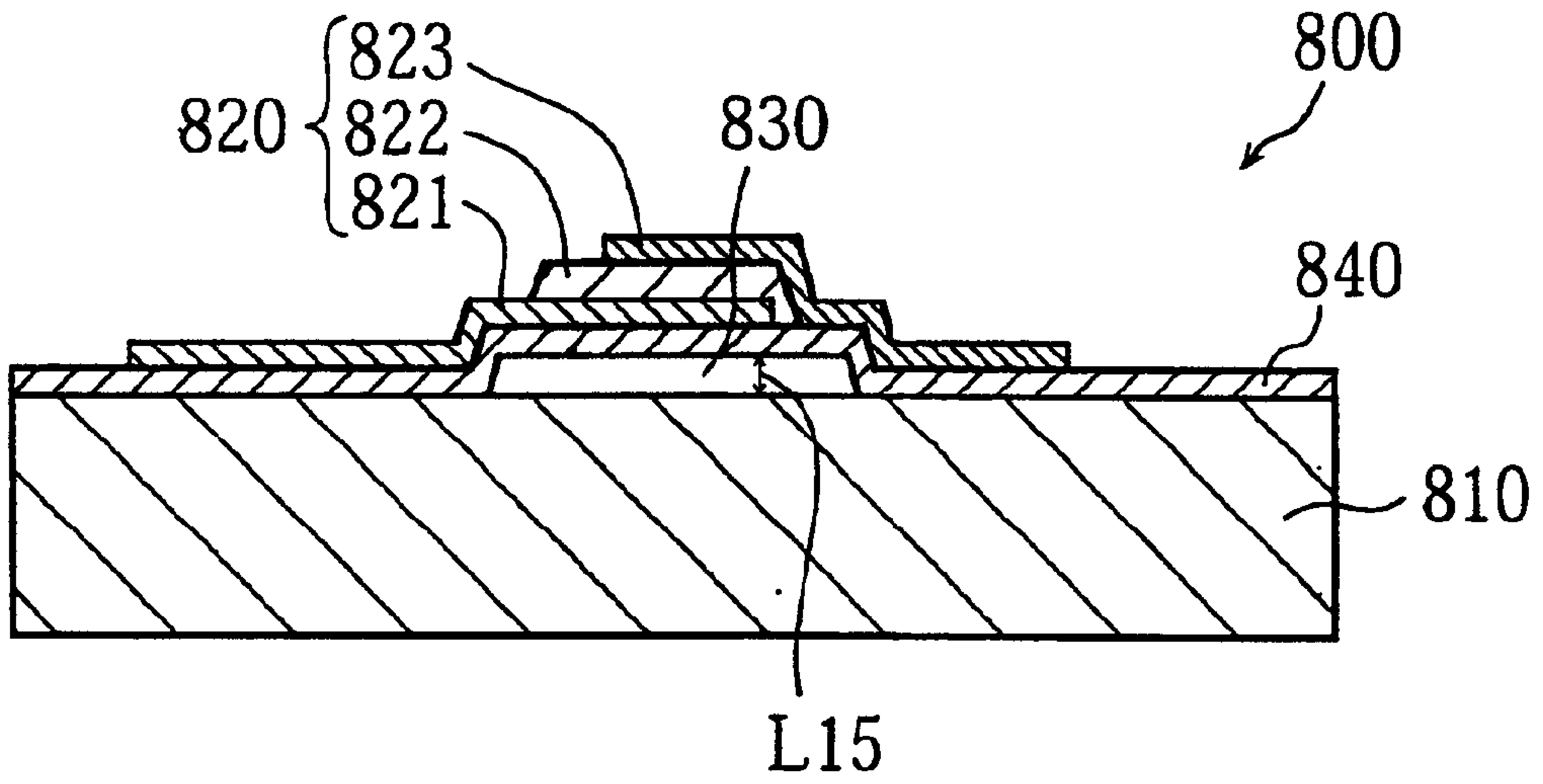
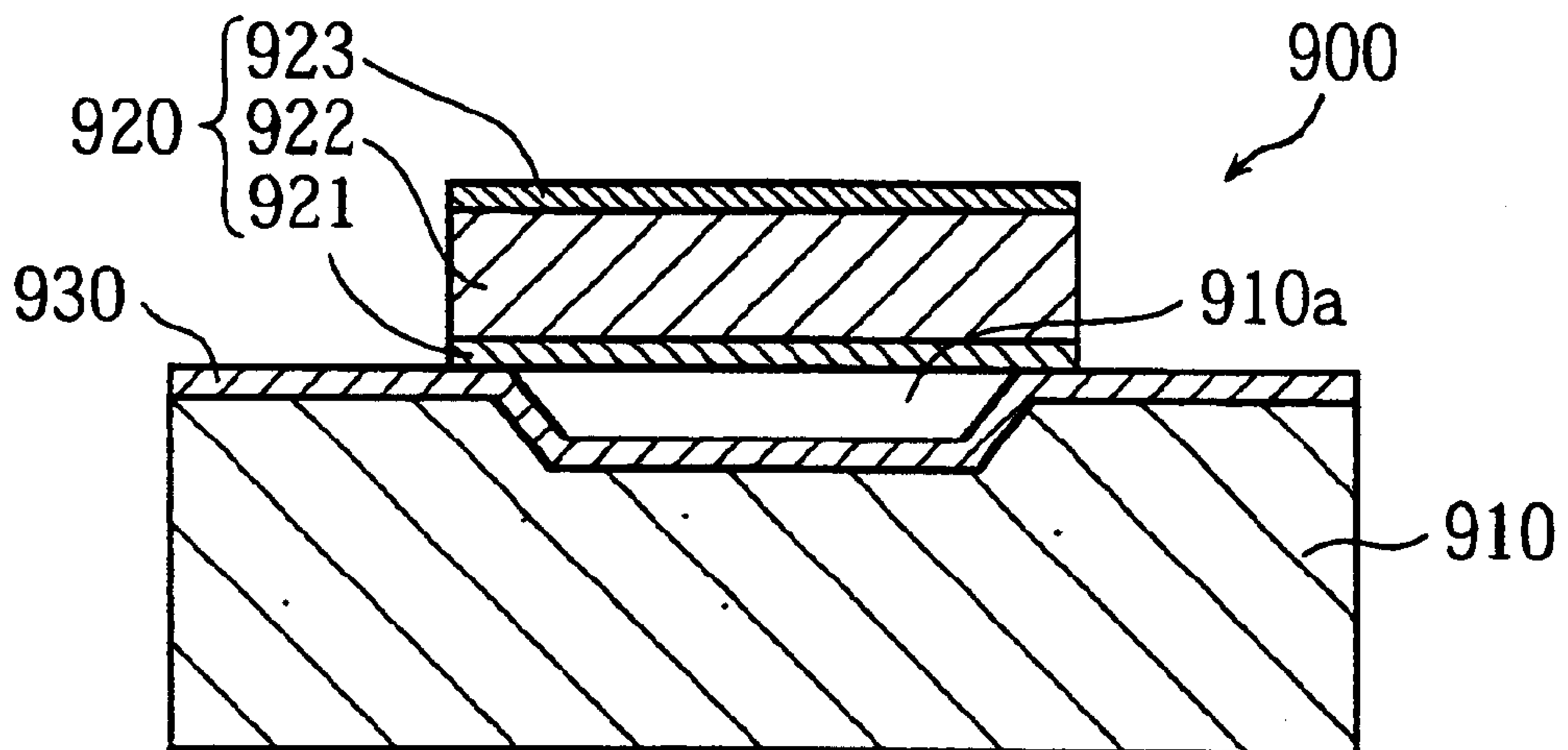


FIG.22
PRIOR ART



THIN-FILM PIEZOELECTRIC RESONATOR, BAND-PASS FILTER AND METHOD OF MAKING THIN-FILM PIEZOELECTRIC RESONATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a thin-film piezoelectric resonator and a method of making the same. The present invention also relates to a band-pass filter utilizing a thin-film piezoelectric resonator (called "piezo-resonator" below).

2. Description of the Related Art

With the rapid spread of mobile telecommunications equipment such as portable telephones, small and light band-pass filters, as well as resonators needed to make such filters, are in great demand. As known in the art, thin-film piezo-resonators are suitable for producing high-power filters.

A typical thin-film piezo-resonator includes a substrate and a resonator assembly mounted on the substrate. The resonator assembly includes a piezoelectric film and a pair of thin electrodes sandwiching the piezoelectric film from above and below. The substrate is formed with a cavity below the lower electrode of the resonator assembly.

When an AC voltage is applied to the upper and the lower electrode of the piezo-resonator, the sandwiched piezoelectric film vibrates in its thickness direction (which is known as the inverse piezoelectric effect). On the other hand, by the direct piezoelectric effect, a mechanical vibration or elastic wave is converted into a corresponding electrical signal. The elastic wave is a longitudinal wave whose main displacement occurs in the thickness direction of the piezoelectric film. In such a thin-film piezo-resonator, the resonator assembly resonates when its thickness H is equal to n/2 times the wavelength of the elastic wave (where n is an integer). Supposing that the propagation velocity of the elastic wave is V (which depends on the material used), the resonance frequency F is expressed by a formula $F=nV/2H$. This means that a piezo-resonator having desired frequency characteristics can be obtained by adjusting the thickness H of the resonator assembly. Further, by connecting such resonators in a ladder configuration, it is possible to produce a band-pass filter which allows only those electric waves lying within a certain frequency range to pass.

In the above-described thin-film piezo-resonator, desired resonance characteristics are attained by providing a cavity or hole below the lower electrode. Techniques suitable to making such a cavity are disclosed in "ZnO/SiO_2-DIAPHRAGM COMPOSITE RESONATOR ON A SILICON WAFER" (K. NAKAMURA, ELECTRONICS LETTERS Jul. 9, 1981 Vol. 17 No. 14 p507–509), JP-A-60 (1985)-189307, JP-A-2000-69594, U.S. Pat. No. 6,060,818 and U.S. Pat. No. 5,587,620 for example.

FIG. **20** shows, in section, a thin-film piezo-resonator disclosed in the above-mentioned "ZnO/SiO_2— DIAPHRAGM COMPOSITE RESONATOR ON A SILICON WAFER". The thin-film piezo-resonator (generally indicated by reference numeral **700**) includes a (100)-cut silicon substrate **710** and a resonator assembly **720** supported by the substrate **710**. The resonator assembly **720** is made up of a lower electrode **721**, a piezoelectric film **722**, and an upper electrode **723**. The silicon substrate **710** has an upper surface upon which a SiO_2 film **711** is formed by thermal oxidation.

The resonator assembly **720** is placed directly on the SiO_2 film **711**. The silicon substrate **710** is formed with a cavity **710***a* whose upper opening is closed by the SiO_2 film **711**. The cavity **710***a* can be produced by anisotropic etching with respect to the (100) surface of the silicon substrate. The anisotropic etching is performed from below the silicon substrate **710** with the use of KOH solution or EDP solution (ethylenediamine+pyrocatechol+water) for example.

The above anisotropic etching relies upon the fact that the etching rate with respect to the (100) surface of the substrate **710** is significantly greater than the etching rate with respect to the (111) surface. Therefore, the resonator assembly is to be provided only on the (100) surface of the substrate **710**. However, such positional limitation is disadvantageous since it restricts the option of the material suitable for making the components of the resonator assembly **720**, while also depriving the resonator assembly components of freedom of orientation. Another disadvantage is that the lower opening of the cavity **710***a* tends to be unduly large due to the nonupright side wall **710***a'* of the cavity **710***a*. In the illustrated arrangement, the side wall **710***a'* corresponds to the (111) surface of the substrate **710** and has an inclination of 54.7 degrees with respect to the (100) surface of the silicon substrate **710**. Due to this, the cavity **710***a* has a large opening in the bottom surface of the silicon substrate **710**. For instance, when the substrate **710** has a thickness of 300 μm, the lower opening of the cavity **710***a* is larger than the upper opening by more than 420 μm. Unfavorably, such a large opening of the cavity **710***a* reduces the mechanical strength of the piezo-resonator **700**. In addition, it contributes to an increase in the overall size of the piezo-resonator **700**. With the use of such oversize piezo-resonators, a compact band-pass filter cannot be obtained. Specifically, when the thickness of the substrate **710** is 300 μm, the lower opening of the cavity **710***a* is larger than the upper opening by more than 420 μm, as noted above. Thus, the distance between the neighboring upper openings should be more than 420 μm. Further, as the distance between the adjacent upper openings increases, the length of the wiring pattern for connecting the adjacent resonator assemblies should also increase. This leads to an increase in the resistance of the wiring pattern. A greater resistance of the wiring pattern can be a major factor that prevents the improvement of the filter characteristics in a high-frequency band.

FIG. **21** shows a thin-film piezo-resonator disclosed in JP-A-60-189307. The piezo-resonator **800** includes a substrate **810**, and a resonator assembly **820** which is made up of a lower electrode **821**, a piezoelectric film **822**, and an upper electrode **823**. A cavity **830** is provided between the substrate **810** and the resonator assembly **820**. According to the Japanese document, the piezo-resonator **800** is fabricated in the following manner. First, a sacrifice layer for the cavity **830** is formed in a pattern on the substrate **810**. Next, a SiO_2 film **840** is formed on the sacrifice layer **840** in a manner such that part of the sacrifice layer is exposed. Then, the resonator assembly **820** is provided on the SiO_2 film **840**. Finally, the sacrifice layer is removed by wet etching, so that the cavity **830** appears below the resonator assembly **820**. According to this method, the cavity **830** is kept from becoming too large with respect to the resonator assembly **820**.

In the thin-film piezo-resonator utilizing a longitudinal vibration in the thickness direction, a high-orientation piezoelectric film is required to provide excellent resonance characteristics. According to the technique disclosed in JP-A-60-189303, however, it is difficult to give a sufficiently high orientation to the piezoelectric film **822**. The cavity **830**

below the resonator assembly **820** has a length L15, which needs to be at least a few micron meters when a twist and oscillation displacement of the resonator assembly **820** are taken into consideration. Unfavorably, the sacrifice layer, formed to have a thickness corresponding to the length L15, has a greater surface roughness than that of the silicon substrate **810**. This deteriorates the orientation of the lower electrode **821** and the piezoelectric film **822** both of which are grown on the sacrifice layer via the SiO_2 film **840**. As a result, it is difficult to obtain good resonance characteristics with the thin-film piezo-resonator.

FIG. **22** is a sectional view of a thin-film piezo-resonator disclosed in JP-A-2000-69594. The thin-film piezo-resonator **900** includes a silicon substrate **910**, and a resonator assembly **920** made up of a lower electrode **921**, a piezoelectric film **922** and an upper electrode **923**. A cavity **910***a* is provided below the resonator assembly **920**. According to this document, to make the thin-film piezo-resonator **900**, the silicon substrate **910** is etched to form a recess serving as the cavity **910***a*. Then, a SiO_2 film **930** is formed by thermal oxidation on a surface of the silicon substrate **910**. Next, material is deposited in the cavity **910***a* to form a sacrifice layer. After the depositing, the surface of the sacrifice layer is polished and cleaned. Next, the resonator assembly **920** is formed on the sacrifice layer in a manner such that the sacrifice layer is partially exposed. Finally, the sacrifice layer is removed by wet etching.

However, the method disclosed in JP-A-2000-69594 includes a large number of steps such as the step of depositing the sacrifice layer in the cavity **910***a*, the step of polishing the sacrifice layer and so on. Therefore, it is difficult to manufacture the thin-film piezo-resonator at a low cost and at a high yield.

SUMMARY OF THE INVENTION

The present invention has been proposed under the circumstances described above. It is, therefore, an object of the present invention to solve or reduce the above conventional problems, and to provide a thin-film piezo-resonator suitable for miniaturization and having a highly oriented piezoelectric film, to provide a band-pass filter including this thin-film piezo-resonator, and to provide a method of making such a thin-film piezo-resonator.

According to a first aspect of the present invention, there is provided a thin-film piezo-resonator comprising: a substrate having a first surface and a second surface opposite to the first surface, the substrate being formed with a cavity that has a first opening in the first surface and a second opening in the second surface; and a resonator assembly including an exciter composed of a first electrode contacting the first surface, a piezoelectric layer on the first electrode and a second electrode on the piezoelectric layer, the assembly being disposed at a location corresponding to the cavity. The cavity includes a side surface extending in a substantially perpendicular direction to the first surface of the substrate.

In this specification, the "exciter" refers to the overlapping region of the first and the second electrodes (or electrode patterns) and the piezoelectric layer.

With the above arrangements, it is possible to fabricate a thin-film piezoelectric resonator that is compact and exhibits excellent resonance characteristics. The compactness results from the cavity that penetrates the substrate in a non-flaring manner, with an uniformly upright side surface. Such a cavity may be produced by dry etching such as Deep-RIE (Reactive Ion Etching), regardless of the cut condition of the substrate. With the use of such compact resonators, a compact filter can be obtained. Further, since the cut condition of the substrate does not affect the formation of the cavity, the most suitable cut surface can be realized in the substrate. The free selectability of the cut surface facilitates the forming of a highly oriented first electrode (lower electrode) thereon. This allows a highly oriented piezoelectric layer to be formed on the first electrode. Accordingly, it is possible to produce a thin-film piezo-resonator with excellent resonance characteristics.

The first electrode and the second electrode may be formed of e.g. aluminum (Al), copper (Cu), molybdenum (Mo), chromium (Cr), titanium (Ti) and platinum (Pt). The piezoelectric layer may be formed of e.g. aluminum nitride (AlN), zinc oxide (ZnO), lead zirconate titanate (PZT), and lead titanate ($PbTi_3$). The substrate may be made of silicon.

Preferably, the first electrode may include a uniaxially oriented single-layer conductive member or uniaxially oriented multi-layer conductive member. In addition, the piezoelectric layer may also be uniaxially oriented. Preferably, the substrate may be a (111)-cut silicon substrate, so that its first and second surfaces are a (111) surface. These arrangements are preferable in providing a highly oriented piezoelectric layer.

Preferably, the first electrode may include a single conductive layer containing either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu. Or, the first electrode may include a stack of uniaxially oriented conductive layers including a first conductive layer held in contact with said first surface, the first conductive layer containing either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu. Or, the first electrode may have a two-layer structure including a first conductive layer and a second conductive layer, where the first conductive layer, held in contact with the first surface of the substrate, contains either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu, while the second conductive layer contains (110)-uniaxially oriented Mo.

With the above arrangement, it is possible to form a highly oriented first electrode on the (111)-cut silicon substrate.

Preferably, the piezoelectric layer may be made of either one of (002)-uniaxially oriented AlN and (002)-uniaxially oriented ZnO for high orientation.

Preferably, the resonator of the present invention may further include a cover substrate for protection of e.g. the resonator assembly. The cover substrate may be bonded to the second surface of the substrate so as to close the cavity.

Preferably, the first electrode and the piezoelectric layer may each include a portion exposed to the cavity. Such exposure is advantageous to providing the resonator with excellent resonance characteristics.

According to a second aspect of the present invention, there is provided a thin-film piezo-resonator that includes: a (111)-cut silicon substrate; a first electrode formed on the substrate and containing either one of Al and Cu; a piezoelectric layer formed on the first electrode and containing either one of AlN and ZnO; and a second electrode formed on the piezoelectric layer. The silicon substrate includes a first surface which is a (111) surface. The first electrode is held in contact with the first surface of the substrate.

According to a third aspect of the present invention, there is provided a thin-film piezo-resonator that includes: a substrate having a first surface and a second surface opposite to the first surface, the substrate being formed with a cavity that has a first opening in the first surface of the substrate; and a resonator assembly including a first electrode contact-

ing the first surface of the substrate, a piezoelectric layer on the first electrode and a second electrode on the piezoelectric layer. The resonator assembly is disposed at a location corresponding to the cavity. Each of the first electrode and the piezoelectric layer includes a portion exposed to the cavity.

With the above arrangements, the resonator assembly exhibits better resonance characteristics than when it is isolated from the cavity. Further, when the opening of the cavity is wide enough to allow not only the first electrode but also the piezoelectric layer to be exposed, resonance characteristics such as the minimum insertion loss or attenuation pole suppression can be improved.

According to a fourth aspect of the present invention, there is provided a filter that includes: a substrate having a first surface and a second surface opposite to the first surface, where the substrate is formed with a plurality of cavities spaced from each other; a first electrode pattern held in contact with the first surface of the substrate; a piezoelectric layer on the first electrode pattern; a second electrode pattern on the piezoelectric layer; and a plurality of resonator assemblies provided by a combination of the first electrode pattern, the piezoelectric layer and the second electrode pattern, where each of the resonator assemblies corresponds in position to one of the cavities. Each of the cavities has a side surface extending in a substantially perpendicular direction to the first surface of the substrate.

Preferably, each of the cavities may include a first opening in the first surface of the substrate and a second opening in the second surface of the substrate, where the distance between adjoining first openings is no greater than 420 μm.

With the above arrangement, it is possible to provide a compact filter. Further, since the connecting distance between any adjoining resonator assemblies can be short, the resistance of the wiring pattern is also reducible. Advantageously, a filter with a less resistive wiring pattern exhibits better performance in a high-frequency band.

In a conventional filter which includes a silicon substrate formed with several cavities (each corresponding in position to one of the piezoelectric resonators), the upper openings of adjoining cavities should be spaced from each other by more than 420 μm (supposing that the thickness of the substrate is 300 μm or more) due to the downward flare of the cavities (see FIG. **20**). According to the present invention, on the other hand, the distance between adjoining first or upper openings is 420 μm or smaller by forming each cavity in a manner such that its side surface extends perpendicularly to the substrate. As a result, the filter of the present invention can be smaller than a conventional filter.

Preferably, the resonator assemblies used for the filter of the present invention may include a first group of resonator assemblies connected in series and a second group of resonator assemblies connected in parallel. This makes the filter a ladder type.

Preferably, the first electrode pattern and the piezoelectric layer may be exposed to one of the cavities.

According to a fifth aspect of the present invention, there is provided a filter that includes: a substrate that has a first surface and a second surface opposite to the first surface and is formed with a plurality of cavities each including a first opening in the first surface of the substrate and a second opening in the second surface of the substrate; a first electrode pattern held in contact with the first surface of the substrate; a piezoelectric layer on the first electrode pattern; a second electrode pattern on the piezoelectric layer; and a plurality of exciters provided by the combination of the first electrode pattern, the piezoelectric layer and the second electrode pattern, where each of the exciters corresponds in position to one of the cavities. The first electrode pattern and the piezoelectric layer each include a portion exposed to one of the cavities.

In the above-mentioned aspects of the present invention, the first and the second openings of the cavity may preferably be circular or oval rather than rectangular. This is because a rectangular opening is more difficult to make than a smoothly curved opening by dry-etching, since the etching rate for the corners of the opening tends to be slower than the etching rate for the other portions. In particular, when several openings of different sizes are to be made in a single substrate, the production efficiency is significantly higher in making arcuate openings than in making rectangular openings.

As noted above, the first electrode or the piezoelectric layer may have a portion exposed to a cavity for better resonance characteristics. Preferably, these exposed portions may be made of a material which is not etched by a fluorine gas. Examples of such material are aluminum and copper. With this arrangement, the first electrode and the piezoelectric layer will not or hardly be damaged in performing Deep-RIE.

In this specification, as defined above, an "exciter" is the overlapping region of the first and the second electrodes (or electrode patterns) and the piezoelectric layer. More specifically, the first electrode includes a "first exciter portion" that overlaps the second electrode. Likewise, the second electrode includes a "second exciter portion" that overlaps the first electrode. In symmetry, the first and the second exciter portions have the same or substantially same configuration. The exciter is the assembly of the first and the second exciter portions and a portion of the piezoelectric layer that is sandwiched between the first and the second exciter portions. Since the first and the second exciter portions are (substantially) the same in shape, the desired capacitance is precisely attained between the first and the second exciter portions. Preferably, each exciter portion as a whole or in part may be circular or oval.

In the first to fifth aspects of the present invention, the area of the first opening of a cavity may preferably be 1~2.25 times larger than the area of the above-defined first or second exciter portion. With this design, the resonator assembly can exhibit good resonance characteristics, while being prevented from suffering deformation or damage.

According to a sixth aspect of the present invention, there is provided a method of making a thin-film piezo-resonator. The method includes the steps of: preparing a substrate including a first surface and a second surface opposite to the first surface; forming a resonator assembly which includes a first electrode held in contact with the first surface of the substrate, a piezoelectric layer formed on the first electrode and a second electrode formed on the piezoelectric layer; and forming a cavity by dry-etching the substrate, where the cavity is disposed at a location corresponding to the resonator assembly, and opened in the first and the second surfaces of the substrate. The cavity includes a side surface extending in a substantially perpendicular direction to the first surface of the substrate.

According to a seventh aspect of the present invention, there is provided a method of making a thin-film piezoresonator. The method includes the steps of: preparing a substrate including a first surface and a second surface opposite to the first surface; forming a resonator assembly which includes a first electrode held in contact with the first

surface of the substrate, a piezoelectric layer formed on the first electrode and a second electrode formed on the piezoelectric layer; and forming a cavity by dry-etching the substrate, where the cavity is disposed at a location corresponding to the resonator assembly, and opened in the first and second surfaces of the substrate. The first electrode and the piezoelectric layer are caused to be partially exposed to the cavity at the cavity-forming step.

In the sixth and the seventh aspects of the present invention, the dry etching may be Deep-RIE. The method may further include the step of bonding a cover substrate to the second surface of the substrate so as to close the cavity. In the method, a groove for dividing the substrate may also be formed by etching at the cavity-forming step.

Other features and advantages of the present invention will become apparent from the detailed description given below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a thin-film piezo-resonator according to a first embodiment of the present invention;

FIG. **2** is a sectional view taken in lines II—II in FIG. **1**;

FIG. **3** shows a one-port, thin-film piezo-resonator subjected to a characteristic evaluation measurement;

FIG. **4** is a graph showing the dependency of minimum insertion loss on L2/L1;

FIG. **5** is a graph showing the dependency of attenuation pole suppression on L2/L1;

FIGS. **6**A~**6**E show several sequential steps for manufacturing the thin-film piezo-resonator in FIG. **1**;

FIGS. **7**A~**7**D show several steps subsequent to the previous steps shown in FIG. **6**;

FIG. **8** is a sectional view of a thin-film piezo-resonator according to a second embodiment of the present invention;

FIG. **9** is a sectional view of a thin-film piezo-resonator according to a third embodiment of the present invention;

FIG. **10** is a plan view showing a thin-film piezo-resonator according to a fourth embodiment of the present invention;

FIG. **11** is a sectional view taken along lines XI—XI in FIG. **10**;

FIG. **12** is a plan view showing a band-pass filter according to a fifth embodiment of the present invention;

FIG. **13** is a sectional view taken along lines XIII—XIII in FIG. **12**;

FIG. **14** is a sectional view taken along lines XIV—XIV in FIG. **12**;

FIG. **15** is a plan view showing a band-pass filter according to a sixth embodiment of the present invention;

FIG. **16** is a sectional view taken along lines XVI—XVI in FIG. **15**;

FIG. **17** is a sectional view taken along lines XVII—XVII in FIG. **15**;

FIG. **18** is a sectional view taken along lines XVIII—XVIII in FIG. **15**;

FIG. **19** is a circuit diagram of a band-pass filter of the present invention;

FIG. **20** is a sectional view of a conventional thin-film piezo-resonator;

FIG. **21** is a sectional view of another conventional thin-film piezo-resonator; and

FIG. **22** is a sectional view of another conventional thin-film piezo-resonator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiments of the present invention will be described below with reference to the accompanying drawings.

FIG. **1** shows a thin-film piezo-resonator **100** according to a first embodiment of the present invention. FIG. **2** is a sectional view taken along lines II—II in FIG. **1**.

The thin-film piezo-resonator **100** includes a silicon substrate **110**, and a resonator assembly **120** formed thereon. The silicon substrate **110** is a (111)-cut monocrystal silicon substrate, and has a first surface **111** and a second surface **112** each provided as a (111) surface. The resonator assembly **120** includes a first electrode film **121**, a second electrode film **122**, and a piezoelectric film **123** sandwiched by these films. According to the present embodiment, the first electrode film **121** has a thickness of 100 nm, and is made of (111)-uniaxially oriented Al or Cu. The second electrode film **122** has a thickness of 100 nm, and is made of Al or Cu. The piezoelectric film **123** has a thickness of 500 nm, and is provided by (002)-uniaxially oriented AlN or ZnO.

The silicon substrate **110** is formed with a cavity **110***a* below the resonator assembly **120**. The cavity **110***a* penetrates the silicon substrate **110** vertically with respect to the first surface **111** and the second surface **112**. The cavity **110***a* has an opening **112***a* on the second surface **112**, which is identical in area and shape to an opening **111***a* on the first surface **111**. In the illustrated example, the openings **111***a* and **112***a* are both square. Since the opening **112***a* of the cavity **110***a* is not significantly larger than the opening **111***a*, it is possible to design the silicon substrate **110**, and hence the thin-film piezo-resonator **100**, to a desirably small size. For example, if the thin-film piezo-resonator **100** is to have a resonance frequency of 5 GHz, the resonator assembly **120** should have an exciter whose length L1 is equal to about 50 μm. The cavity **110***a* has a length L2 equal to about 60 μm. The "exciter" refers to a region overlapped by the first electrode film **121** and the second electrode film **122** via the piezoelectric film **123**. In the illustrated example, the exciter has a square configuration whose side has a length L1. According to the present invention, the exciter may have a rectangular or other configuration. In conformity with the exciter, the openings **111***a*, **112***a* may be modified in configuration. In the illustrated example, the first electrode **121** and the piezoelectric film **123** are partially exposed to the cavity **110***a*. This provides the piezo-resonator **100** with excellent resonance characteristics.

Description will now given to the influence of the length L1 (of the exciter) and the length L2 (of the cavity **110***a* or the opening **111***a*) on the resonance characteristics. A single-port resonator provided by the thin-film piezo-resonator **100** was connected to a network analyzer, as shown in FIG. **3**. The passing characteristics (S21 characteristics) were measured. FIG. **4** and FIG. **5** show the results of the measurement. The thin-film piezo-resonators **100** used for the measurement ware made up of a (111)-cut 300 μm-thick silicon substrate **110**, and a resonator assembly **120** which includes a 100 nm-thick first electrode film **121** made of Al, a 500 nm-thick piezoelectric film **123** made of ZnO, and a 100 nm-thick second electrode film **122** made of Al. With the piezo-resonators **100**, the ratio of the length L1 to the length L2 is not the same. FIG. **4** is a graph showing the dependency of minimum insertion loss on L2/L1. FIG. **5** is a graph showing the dependency of attenuation pole suppression on L2/L1.

According to the graph in FIG. **4**, the minimum insertion loss increases when L2/L1 is smaller than 1, but remains

generally constant when L2/L1 is no smaller than 1. According to the graph in FIG. **5**, the attenuation pole suppression decreases when L2/L1 is smaller than 1, but remains generally constant when L2/L1 is no smaller than 1. As suggested by the minimum insertion loss and the attenuation pole suppression, the resonance characteristics are excellent when L2/L1 is no smaller than 1. This is because both the first electrode **121** and the piezoelectric film **123** are partially exposed to the cavity **110***a* when L2/L1 is no smaller than 1 (when L2/L1 is smaller than 1, only the first electrode **121** is exposed to the cavity **110***a*). However, when L2/L1 is greater than 1.5, the exciter can readily warp. Unfavorably, this may increase the alteration factors of the resonance characteristics and also make the resonator **100** more vulnerable to damage.

Therefore, L2/L1 must be no smaller than 1, but as small as possible in consideration of the accuracy of the manufacturing process. Preferably, L2/L1 should be in a range of 1~1.5.

For the measurements, the exciter has a square configuration whose side is L1 in length, and the opening **111***a* also has a square configuration whose side is L2 in length. Since the preferable value of the L2/L1 is in a range of 1~1.5, the areal ratio of the opening **111***a* to the exciter should be in a range of 1~2.25. This holds for a case where neither the opening **111***a* nor the exciter is square.

Next, description will be given to the influence which the condition of the silicon substrate surface exerts on the orientation of the first electrode film and the piezoelectric film formed on the substrate. For comparison, four substrates A, B, C and D were prepared. The substrate A was a (111)-cut silicon substrate. The substrate B was a (100)-cut silicon substrate. The substrate C was a (111)-cut silicon substrate formed with a 5-micrometer-thick SiO_2 film by sputtering. The substrate D was a (100)-cut silicon substrate formed with a 5-micrometer-thick SiO_2 film by sputtering. Then, each substrate was formed with a 100 nm-thick Al film as the first electrode film by sputtering. Further, an piezoelectric film of ZnO was formed by sputtering on the first electrode film to have a thickness of 500 μm. Then, for each substrate, the orientation of the Al and ZnO in the formed film was checked. Specifically, the orientation was evaluated based on the FWHM (Full Width at Half Maximum) value of a rocking curve obtained through X-ray diffraction. A higher FWHM value means a higher orientation. In order to provide good piezoelectric characteristics, the piezoelectric film preferably has an FWHM value smaller than 6 degrees.

Table 1 shows FWHM values of the (111)-uniaxially oriented Al and the (002)-uniaxially oriented ZnO for the Al or ZnO films formed on the substrates A, B, C and D.

TABLE 1

	Al	ZnO
Substrate A	0.71°	0.86°
Substrate B	13.2°	7.4°
Substrate C	Nonmeasurable	Nonmeasurable
Substrate D	Nonmeasurable	Nonmeasurable

As shown in Table 1, in the substrate A, the Al showed a good (111) uniaxial orientation, and the ZnO showed a good (002) uniaxial orientation. The "uniaxial orientation" here means that in a result of a θ-2θ measurement in the X-ray diffraction, diffraction peak intensity from undesired crystal surfaces is not greater than 1/100 of diffraction peak intensity from the desired crystal surface. In the substrate B, relatively strong diffraction peaks were observed from other crystal surfaces such as Al (200) and the ZnO (103), showing that no sufficient uniaxial orientation was realized in the Al-layer as the first electrode and in the ZnO-layer as the piezoelectric film. As shown, the substrate A made by (111) cutting has a smaller FWHM values for Al (111) and ZnO (002) than the substrate B made by (100) cutting, indicating that the orientation is high in both the Al-layer as the first electrode and the ZnO layer as the piezoelectric film. As for the substrates C and D, the SiO_2 film formed on the substrate has a very rough surface, so that the orientations in the Al and ZnO films cannot be measured

For the substrates A and B, additional orientation checking was performed in the same manner as described above. This time, the substrates A and B were provided with a 100 nm-thick Cu film as the first electrode and with a 500 nm-thick ZnO film as the piezoelectric film. The additional checking revealed that in the substrate A, Cu showed good (111) uniaxial orientation, whereas ZnO showed good (002) uniaxial orientation. In particular, the ZnO film as the piezoelectric film showed a FWHM value of 1.8° in the substrate A and 9.6° in the substrate B. This result indicates that ZnO as the piezoelectric film in the substrate A has a higher orientation than ZnO in the substrate B. Further, another orientation checking was performed for the substrates A and B in which a 50 nm-thick Al and an additional 100 nm-thick Mo film were formed as the first electrode, and a 500 nm-thick AlN film was formed as the piezoelectric film. The results are that in the substrate A, Al showed good (111) uniaxial orientation, Mo showed good (110) uniaxial orientation, and AlN showed good (002) uniaxial orientation. In the substrate B, a diffraction peak from a crystal surface such as Mo (211) was observed in the Mo layer of the first electrode, which reveals that there was not good uniaxial orientation. In particular, the AlN film formed as the piezoelectric film showed a FWHM value of 2.1° for the substrate A, whereas the value was nonmeasurable for the substrate B.

The above result show that the substrates A and B (that is, the silicon substrate formed with no SiO_2 film) are more suitable for the formation of oriented piezoelectric film than the substrates C and D which are formed with SiO_2 films. Further, it is understood that the substrate A, a (111)-cut silicon substrate, is more suitable for the formation of a highly oriented piezoelectric film than the substrate B, a (100)-cut silicon substrate.

FIGS. **6**A~**6**E and **7**A~**7**D show essential steps in the manufacturing processes of the piezo-resonator **100** shown in FIG. **1**. The sectional views shown in these figures are taken along the lines II—II in FIG. **1**.

Specifically, as shown in FIG. **6**A, a first electrode film **121** is formed on a silicon wafer **10** by sputtering. The thickness of the resultant film **121** is 100 nm. The silicon wafer **10** is a (111)-cut wafer. A first surface **11** and a second surface **12** of the wafer **10** are a (111) surface. The first electrode film is made of Al or Cu. Referring to FIG. **6**B, dry etching or wet etching is performed via a patterned resist layer (not shown) to pattern the first electrode film **121**. For the dry etching, use may be made of a gas mixture of BCl_3 and Cl_2 for Al, and a gas mixture of Ar and Cl_2 for Cu. In the wet etching, for Al, the etching solution may be a water solution containing phosphoric acid, acetic acid and nitric acid, while for Cu, it may be a water solution of ceric ammonium nitrite. These can be used for the subsequent etching processes.

Next, as shown in FIG. **6**C, sputtering is performed to form a piezoelectric film **123** to a thickness of 500 μm, and

a second electrode film **122** to a thickness of 100 nm. The piezoelectric film **123** is made of AlN or ZnO. The second electrode film **122** is made of Al or Cu. Next, as shown in FIG. **6D**, dry etching or wet etching is performed via a resist pattern, to pattern the second electrode film **122**. Next, as shown in FIG. **6E**, dry etching or wet etching is performed via a mask, to pattern the piezoelectric film **123**. In the wet etching, heated phosphoric acid can be used as the etching solution for AlN, and a water solution of acetic acid can be used for ZnO. The patterning of the piezoelectric film **123** leaves a resonator assembly **120** on each region to be the resonator device.

In the above method, the resonator assembly **120** is produced through a resist film forming step, light exposure to the resist, and etching for the electrode film and the piezoelectric film. According to the present invention, alternatively, the resonator assembly **120** may be produced through a resist film forming step, light exposure to the resist, an electrode/piezoelectric film forming step and a lift-off step.

Next, as shown in FIG. **7A**, a resist **30** is formed on the first surface **11** of the silicon wafer **10**. The resist **30** protects the resonator assembly **120** in the subsequent steps.

Next, as shown in FIG. **7B**, a resist pattern **20** is formed on the silicon wafer **10**. Specifically, a photo-resist film is formed on the second surface **12** of the silicon wafer **10**. The photo-resist film is then exposed and developed to leave the resist pattern **20**.

Next, as shown in FIG. **7C**, the silicon wafer **10** is subjected to Deep-RIE, which is a dry etching, via the resist pattern **20**. This step leaves a cavity **110*a*** in each of the resonator device. In the Deep-RIE, etching and sidewall protection are performed alternately. For instance, etching with SF_6 gas is performed for about 10 seconds, to be followed by sidewall protection with C_4F_8 gas which is performed for about 10 seconds. The bias applied to the wafer is about 20 W. This forms the cavity **110*a*** that is generally vertical to the first surface **11** and second surface **12** of the silicon wafer **10**. In the dry etching with the use of fluoric gas, advantageously, Al, Cu, AlN and ZnO are not etched away. Thus, the cavity **110*a*** can be produced without damaging the first electrode **121** and the piezoelectric film **122**. In the dry etching, Al, Cu, AlN and ZnO serve as a stopper for the etching process.

Additionally, according to the present invention, in the step of forming the cavity **110*a***, split grooves for separating the wafer into device elements may be formed. This eliminates a dicing step otherwise necessary for dividing the wafer, thereby facilitating the manufacturing of the thin-film piezo-resonator **100**.

Referring to FIG. **7D**, the resist pattern **20** and the resist **30** are removed. Then, through the dicing step, a plurality of thin-film piezo-resonators are obtained.

FIG. **8** is a sectional view of a thin-film piezo-resonator according to a second embodiment of the present invention. The piezo-resonator **200** includes a first electrode **221** and a second electrode **222**. As seen from the figure, the first electrode **221** has a two-fold structure which includes a first conductive layer **221*a*** and a second conductive layer **221*b***. The first conductive layer **221*a*** has a thickness of 50 nm, and is made of (111)-uniaxially oriented Al or Cu. The second conductive layer **221*b*** has a thickness of 100 nm, and is made of (110)-uniaxially oriented Mo. The second electrode **222** has a thickness of 100 nm, and is made of Mo.

To make the piezo-resonator **200**, the step shown in FIG. **6A** is replaced by a step in which the first and the second conductive layers **221*a***, **221*b*** are formed in a stacking manner. Then, in the next step (corresponding to the step shown in FIG. **6B**), the first and the second conductive layers **221*a***, **221*b*** are subjected to patterning together. The wet etching for this patterning and the wet etching for patterning the second electrode **222** may be performed with etchant such as a water solution containing phosphoric acid, acetic acid and nitric acid. Except for the above-mentioned difference, the piezo-resonator **200** of the second embodiment is similar in arrangement to the piezo-resonator **100** of the first embodiment, and therefore can be fabricated in a similar manner.

In the piezo-resonator **200** again, it is possible to form the highly oriented piezoelectric film **123** of e.g. AlN and ZnO on the (111)-cut silicon substrate **110**.

According to the present invention, the first electrode may be composed of a single conductive layer or multiple conductive layers each of which is uniaxially oriented. In the latter case, the lowest conductive layer (the one held in direct contact with the silicon substrate **110**) is preferably provided by (111)-uniaxially oriented Al or Cu.

FIG. **9** shows, in section, a thin-film piezo-resonator according to a third embodiment of the present invention. The illustrated piezo-resonator **300** includes a piezo-resonator **100** as shown in FIG. **2** and a 200 μm-thick cover substrate **50** attached to the resonator **100** so as to close the cavity **110*a***. More specifically, the cover substrate **50** has an upper surface formed with a Au—Sn film **51** as a bonding layer. The Au—Sn film **51** has a thickness of 5 μm and is produced by sputtering for example. The cover substrate **50** is attached to the second surface **112** of the silicon substrate **110** via the Au—Sn film **51**. The silicon substrate **110** and the cover substrate **50** will be secured to each other after they are heated up and kept at about 310° C. for 30 minutes.

The cover substrate structure described above protects the resonator assembly **120** from being damaged through the resonator fabrication process. For instance, when the second surface **112** is to be bonded to a motherboard with conductive paste, the cover substrate **50** prevents the paste from penetrating into the cavity **110*a***. Also, the cover substrate **50** keeps the first electrode **121** or piezoelectric film **123** from being damaged when the resonator **300** is sucked up by a suction collet for performing flip chip bonding.

According to the present invention, the bonding material may not necessarily be Au—Sn film. A different kind of metal material or resin material (such as epoxy) may be used. Further, without relying on a bonding paste, direct bonding or anodic bonding may be employed for fixing the cover substrate **50** to the silicon substrate **110**.

FIGS. **10** and **11** show a thin-film piezoelectric resonator **400** according to a fourth embodiment of the present invention. FIG. **10** is a plan view, while FIG. **11** is a sectional view taken along lines XI—XI.

The resonator **400** includes a silicon substrate **410** and a resonator assembly **420** formed on the substrate. The substrate **410** is a (111)-cut monocrystal silicon substrate and includes a first surface **411** and a second surface **412** both of which are a (111) surface. The resonator assembly **420** is composed of a first electrode **421**, a second electrode **422** and a piezoelectric film **423** disposed between these electrodes. The first and the second electrodes **421**, **422** include circular electrode portions **421*a*** and **422*a***, respectively. As seen from FIG. **11**, the circular electrode portions **421*a***, **422*a*** are of the same size and aligned vertically, with the piezoelectric film **423** intervening therebetween. The combination of the electrode portions **421*a*** and **422*a*** serves as

the exciter of the resonator **400**. In the illustrated example, the diameter L1' of the exciter is about 50 μm. The first electrode **421**, the second electrode **422** and the piezoelectric film **423** of the fourth embodiment are identical in thickness and material to the counterparts of the resonator **100** according to the first embodiment.

The silicon substrate **410** is formed with a cavity **410***a* located immediately below the exciter of the resonator **420**. The cavity **410***a* extends through the substrate **410** perpendicularly to the first and the second surfaces **411**, **412**. The cavity **410***a* has a first circular opening **411***a* opened in the first surface **411** and a second circular opening **412***a* opened in the second surface **412**. In the illustrated example, the constant diameter L2' of the cavity **410***a* is about 60 μm. With this arrangement, the resonator **400** can be made compact since the second opening **412***a* is not larger than the first opening **411***a* (cf. the conventional resonator **700** of FIG. **20**). As shown in FIG. **11**, the circular electrode portion **421***a* and the piezoelectric film **423** are exposed to the cavity **410***a*, which is advantageous to provide excellent resonance characteristics. The resonator **400** may be fabricated in the same manner as the resonator **100**.

FIGS. **12**~**14** show a band-pass filter **500** according to a fifth embodiment of the present invention. FIG. **12** is a plan view, while FIG. **13** is a sectional view taken along lines XIII—XIII in FIG. **12**, and FIG. **14** is a sectional view taken along lines XIV—XIV in FIG. **12**.

The band-pass filter **500** includes a silicon substrate **110** upon which are provided a first electrode pattern **121**, a second electrode pattern **122** and a piezoelectric film **123** disposed between the first and the second electrode patterns. These three elements are so arranged as to form four thin-film piezoelectric resonators **100**A (connected in series) and four thin-film piezoelectric resonators **100**B (connected in parallel). Each of the resonators **100**A and **100**B corresponds to the resonator **100** of the first embodiment. For connection to an external device, circuit, etc., the first electrode pattern **121** includes a pair of exposed terminal portions **60**A and another pair of exposed terminal portions **60**B. In order to make the resonance frequency of the serial resonators **100**A significantly different from that of the parallel resonators **100**B, the parallel resonators **100**B may be covered with a 50 nm-thick aluminum layer formed on the second electrode pattern **122**. The band-pass filter **500** is a ladder type filter in which eight thin-film piezoelectric resonators **100**A, **100**B are integrally provided on a single silicon substrate **110**. FIG. **19** is a circuit diagram of the band-pass filter **500**.

As shown in FIG. **12**, each resonator **100**A has a square exciter whose side length L**3** is 75 μm. The corresponding cavity **110***a*, as shown in FIG. **13**, has a square opening whose side length L**5** is 80 μm. The clearance L6 between the cavities **110***a* of the adjacent resonators **100**A is 20 μm. In the resonator **100**B, the side length L4 of the square exciter is 50 μm. The corresponding cavity **110***a*, as shown in FIG. **14**, has a square opening whose side length L7 is 55 μm. The clearance L**8** between the cavities **110***a* of the adjacent resonators **100**B is 45 μm. In the band-pass filter **500**, each cavity **110***a* corresponds in position to the exciter of a resonator **100**A or **100**B, wile also extending perpendicularly to the first surface **111** of the substrate **110**. Accordingly, the respective resonator assemblies **120** (and hence the resonators **100**A, **100**B) can be disposed closer to each other than is conventionally possible, which is advantageous to making the band-pass filter compact. Further, the close arrangement of the resonator assemblies **120** advantageously reduces the resistance of the wiring pattern between them.

As shown in FIG. **13**, the first electrode pattern **121** and the piezoelectric film **123** for each resonator **100**A are partially exposed to the corresponding cavity **110***a*. This holds for each of the parallel resonators **100**B. Such exposure ensures excellent resonance characteristics for the respective resonators **100**A, **100**B. Accordingly, the band-pass filter **500** also has excellent resonance characteristics. The band-pass filter **500** may be fabricated in substantially the same manner as the resonator **100** of the first embodiment. More precisely, the fabrication method of the resonator **100** may be modified in a manner obvious to the person skilled in the art so that the predetermined number of resonators **100** will be integrally formed on the same substrate.

In accordance with the present invention, the first electrode pattern may be a laminate of a 50 nm-thick aluminum layer and a 100 nm-thick molybdenum layer, while the second electrode pattern may be a single, 100 nm-thick molybdenum layer, as in the resonator **200** of the second embodiment (FIG. **8**). Further, as in the resonator **300** of the third embodiment (FIG. **9**), a cover substrate may be attached to the substrate **110** from below.

FIGS. **15**~**18** show a band-pass filter **600** according to a sixth embodiment of the present invention. FIG. **15** is a plan view, while FIGS. **16**, **17** and **18** are a sectional view taken along lines XVI—XVI, XVII—XVII and XVIII—XVIII in FIG. **15**, respectively.

The band-pass filter **600** includes a silicon substrate **410** upon which are provided a first electrode pattern **421**, a second electrode pattern **422** and a piezoelectric film **423** disposed between these electrode patterns. As in the fifth embodiment described above, the electrode patterns **421**, **422** and the piezoelectric film **423** are arranged to produce four serially-connected resonators **400**A and four parallel resonators **400**B. Each of the resonators **400**A and **400**B corresponds to the resonator **400** of the fourth embodiment (FIGS. **10** and **11**). For connection to an external device, a circuit, etc., the first electrode pattern **421** includes a pair of terminal portions **70**A and another pair of terminal portions **70**B. As in the previous embodiment, preferably the parallel resonators **400**B are covered with a 50 nm-thick aluminum layer (formed on the second electrode pattern **422**) for significantly differentiating the resonance frequency of the serial resonators **400**A from that of the parallel resonators **400**B. The band-pass filter **600** is a ladder type filter in which eight thin-film piezoelectric resonators **400**A, **400**B are integrally provided on a single silicon substrate **410**. The band-pass filter **600** is also represented by the circuit diagram shown in FIG. **19**.

The diameter L**9** (FIG. **15**) of the circular exciter of the resonator **400**A is 85 μm, while the diameter L**11** (FIG. **16**) of the opening of the corresponding cavity **410***a* is 90 μm. The distance L**12** (FIG. **16**) between the cavities **410***a* of the adjacent resonators **400**A is 20 μm. The length L**10** (FIG. **15**) of the exciter of the resonator **400**B is 55 μm. As shown in FIGS. **17** and **18**, the diameter L13 of the opening of the corresponding cavity **410***a* is 60 μm. The distance L**14** (FIG. **17**) between the cavities **410***a* of the adjacent resonators **400**B is 50 μm. As in the previous embodiment, the band-pass filter **600** can be made compact by disposing the resonator assemblies **420** close to each other.

As shown in FIGS. **16** and **17**, the first electrode pattern **421** and the piezoelectric film **423** for each resonator **400**A or **400**B are partially exposed to the corresponding cavity **410***a*. Such exposure ensures excellent resonance characteristics for the respective resonators **400**A, **400**B.

Accordingly, the band-pass filter **600** also has excellent resonance characteristics. The band-pass filter **600** may be fabricated in substantially the same manner as the resonator **100** of the first embodiment. More precisely, the fabrication method of the resonator **100** may be modified in a manner obvious to the person skilled in the art so that the predetermined number of resonators **400** will be integrally formed on the same substrate.

In accordance with the present invention, the first electrode pattern may be a laminate of a 50 nm-thick aluminum layer and a 100 nm-thick molybdenum layer, while the second electrode pattern may be a single, 100 nm-thick molybdenum layer, as in the resonator **200** of the second embodiment (FIG. **8**). Further, as in the resonator **300** of the third embodiment (FIG. **9**), a cover substrate may be attached to the substrate **410** from below. The exciter may be elliptical or oval rather than circular.

The fifth and sixth embodiments relate to band-pass filters, as described above. It should be noted that the thin-film piezoelectric resonators of the present invention can be used for providing a high-pass filter or low-pass filter.

The present invention being thus described, it is obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the present invention, and all such modifications as would be obvious to those skilled in the art are intended to be included within the scope of the following claims.

What is claimed is:

1. A thin-film piezo-resonator comprising:

a substrate having a first surface and a second surface opposite to said first surface, the substrate being formed with a non-filled cavity that has a first opening in said first surface and a second opening in said second surface; and

a resonator assembly including an exciter composed of a first electrode contacting said first surface, a piezoelectric layer on the first electrode and a second electrode on the piezoelectric layer, the assembly being disposed at a location corresponding to the cavity;

wherein the cavity is located immediately under the resonator assembly and has a side surface extending in a substantially perpendicular direction to the first surface.

2. The resonator according to claim **1**, wherein the first electrode comprises a uniaxially oriented single-layer conductive member or uniaxially oriented multi-layer conductive member.

3. The resonator according to claim **2**, wherein the piezoelectric layer is uniaxially oriented.

4. The resonator according to claim **1**, wherein the substrate is a (111)-cut silicon substrate, said first surface and said second surface each being a (111) surface.

5. The resonator according to claim **4**, wherein the first electrode comprises a single conductive layer containing either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu.

6. The resonator according to claim **4**, wherein the first electrode comprises a stack of uniaxially oriented conductive layers including a first conductive layer held in contact with said first surface, the first conductive layer containing either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu.

7. The resonator according to claim **4**, wherein the first electrode has a two-layer structure comprising a first conductive layer and a second conductive layer, the first conductive layer held in contact with said first surface and containing either one of (111)-uniaxially oriented Al and (111)-uniaxially oriented Cu, the second conductive layer containing (110)-uniaxially oriented Mo.

8. The resonator according to claim **4**, wherein the piezoelectric layer is made of either one of (002)-uniaxially oriented AlN and (002)-uniaxially oriented ZnO.

9. The resonator according to claim **1**, further comprising a cover substrate bonded to said second surface of the substrate so as to close the cavity.

10. The resonator according to claim **1**, wherein each of the first and the second openings has a circular or oval configuration.

11. A thin-film piezo-resonator comprising:

a substrate having a first surface and a second surface opposite to said first surface, the substrate being formed with a cavity that has a first opening in said first surface and a second opening in said second surface; and

a resonator assembly including an exciter composed of a first electrode contacting said first surface, a piezoelectric layer on the first electrode and a second electrode on the piezoelectric layer, the assembly being disposed at a location corresponding to the cavity;

wherein the cavity includes a side surface extending in a substantially perpendicular direction to said first surface; and

wherein each of the first electrode and the piezoelectric layer includes a portion exposed to the cavity.

12. The resonator according to claim **11**, wherein the exposed portion of the first electrode and the exposed portion of the piezoelectric layer are made of a material which is not etched by a fluorine gas.

13. A thin-film piezo-resonator comprising:

a (111)-cut silicon substrate;

a first electrode formed on the substrate and containing either one of Al and Cu;

a piezoelectric layer formed on the first electrode and containing either one of AlN and ZnO; and

a second electrode formed on the piezoelectric layer;

wherein the silicon substrate includes a first surface which is a (111) surface, the first electrode being held in contact with said first surface.

14. A thin-film piezo-resonator comprising:

a substrate having a first surface and a second surface opposite to said first surface, the substrate being formed with a cavity that has a first opening in said first surface; and

a resonator assembly including a first electrode contacting said first surface, a piezoelectric layer on the first electrode and a second electrode on the piezoelectric layer, the assembly being disposed at a location corresponding to the cavity;

wherein each of the first electrode and the piezoelectric layer includes a portion exposed to the cavity.

15. The resonator according to claim **14**, wherein the first and the second electrodes comprise first and second exciter portions, respectively, that define the exciter, the first opening being greater in area than the exciter portions by a factor of 1~2.25.

16. The resonator according to claim **15**, wherein the first exciter portion and the second exciter portion are substantially identical in shape.

17. The resonator according to claim **15**, wherein each of the first and the second exciter portions is at least partially circular or oval.

18. A filter comprising:

a substrate having a first surface and a second surface opposite to said first surface, the substrate being formed with a plurality of non-filled cavities spaced from each other;

a first electrode pattern held in contact with said first surface;

a piezoelectric layer on the first electrode pattern;

a second electrode pattern on the piezoelectric layer; and

a plurality of resonator assemblies provided by a combination of the first electrode pattern, the piezoelectric layer and the second electrode pattern, each of the resonator assemblies corresponding in position to one of the cavities;

wherein each of the cavities is located immediately under a corresponding one of the resonator assemblies and has a side surface extending in a substantially perpendicular direction to said first surface.

19. The filter according to claim 18, wherein each of the cavities includes a first opening in said first surface and a second opening in said second surface, a distance between adjoining first openings being no greater than 420 μm.

20. The filter according to claim 18, wherein said plurality of resonator assemblies include a first group of resonator assemblies connected in series and a second group of resonator assemblies connected in parallel.

21. The filter according to claim 18, wherein the first electrode pattern and the piezoelectric layer are exposed to one of the cavities.

22. A filter comprising:

a substrate having a first surface and a second surface opposite to said first surface, the substrate being formed with a plurality of cavities each including a first opening in said first surface and a second opening in said second surface;

a first electrode pattern held in contact with said first surface;

a piezoelectric layer on the first electrode pattern;

a second electrode pattern on the piezoelectric layer; and

a plurality of exciters provided by a combination of the first electrode pattern, the piezoelectric layer and the second electrode pattern, each of the exciters corresponding in position to one of the cavities;

wherein the first electrode pattern and the piezoelectric layer each include a portion exposed to one of the cavities.

23. The filter according to claim 22, wherein the exposed portions of the first electrode pattern and the piezoelectric layer are made of a material which is not etched by a fluorine gas.

24. The filter according to claim 22, wherein each of the exciters is defined by a first exciter portion and a second exciter portion contained respectively in the first electrode pattern and the second electrode pattern, the first exciter portion and the second exciter portion being substantially identical in shape.

25. The filter according to claim 24, wherein the first opening of the cavity corresponding to said each exciter is greater in area than the exciter portions by a factor of 1~2.25.

26. The filter according to claim 22, Wherein the first and the second openings of each cavity are circular or oval.

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